

**OBSERVATIONS OF POST TSUNAMI
RECONNAISSANCE INVESTIGATIONS ALONG
EASTERN COASTAL TRACT OF INDIA
FOLLOWING THE DEVASTATING TSUNAMI OF
26TH DECEMBER 2004**

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EXECUTIVE SUMMARY

Many coastal regions of India were affected by the tsunami caused by a magnitude 9 earthquake off Sumatra on 26th December 2004. This report presents the observations of post-tsunami reconnaissance survey conducted by the National Institute of Oceanography, Dona Paula, Goa, along the most affected coastal stretch of Tamil Nadu, Pondicherry and southern Andhra Pradesh. The surveyed coastal tract is about 450 km long and lies between Vedaranyam (Tamil Nadu) in the south and Krishnapatnam (Andhra Pradesh) in the north. The objective of the study was to observe and document the readily available and perishable data which contains information about the nature and impact of the phenomenon. This information is expected to be helpful for planning, preparedness and identifying further research needs.

To fulfill the above objective, the survey covered various aspects of tsunami such as run-up, inundation, tsunami transported sediments, tsunamigenic structural failures and other damages and collection of eyewitnesses account about nature of tsunami on arrival, etc.

The survey revealed that the maximum inundation limit was about 862 m at Nagore and the minimum about 31 m at Kottaikadu Kuppam. Maximum run-up of about 6.54 m (above chart datum) was observed at Periyakalpet (north of Pondicherry) and the minimum of about 2.198 m at Krishnapatnam (Andhra Pradesh). The tsunami traveled along the river course several kilometers upstream. The bearing of tsunami on the coast was about 240° in the areas south of Samanthanpettai and in the areas northwards from here, in general, it veered towards 270° or more.

Majority of observed structural failures appear to be mainly due to very close proximity to sea, inferior design and poor quality of construction. Natural and

artificial barriers were found to have diffused the energy of tsunami to considerable level. Both the erosion and deposition were associated with the tsunami and at places tsunami transported sediments contained black sand layers. Eyewitnesses report suggests that there were three distinguishable pulses of tsunami and their magnitude and period appear to have been different at different sites. In many places the second wave appeared as the biggest. The withdrawal of sea associated with tsunami appears to have been distinctly noticeable in the areas northwards from Pondicherry.

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Section –1

GENERAL BACKGROUND

1.1 Introduction

On 26th December 2004 the Indian coastline experienced the most devastating tsunami in recorded history. The tsunami was triggered by an earthquake of magnitude 9.0 on the Richter scale at 3.4° N, 95.7° E off the coast of Sumatra in the Indonesian Archipelago at 06:29 hrs IST (00:59 hrs GMT). The tsunami swept into the Indian coastline about two hours after the seismic event and caused extensive damage to life and property.

Subsequently, the National Institute of Oceanography, Goa, initiated several post-tsunami studies. As part of those exercises, post-tsunami reconnaissance investigations were carried out along the most affected coastal stretches of Tamil Nadu, Pondicherry, Southern Andhra Pradesh and Kerala. This report pertains to the field observations carried out in this context on the east coast of India along a coastal stretch of about 450 km from Vedaranyam (Southern Tamil Nadu) in the south to Krishnapatnam (Southern Andhra Pradesh) in the north.

1.2 Objective and scope of study

The objective of the study was to observe and document the effects of the tsunami on the coastal tract, by collecting readily available and perishable data, so as to learn about the nature and impact of the phenomenon. This information is expected to be helpful for planning, preparedness and identifying further research needs.

The scope of the present investigation covers the following:

- i) Inundation & Run-up measurement
- ii) Sampling tsunami transported sediments
- iii) Observe tsunamigenic structural failures and other damages
- iv) Collect information about tsunami characteristics from eyewitnesses
- v) Littoral Environmental Observations
- vi) Analysis of post tsunami coastal surface sea water quality

1.3 Study area:

The present study was carried out in the east coast of India (Fig. 1). During this field work a total of 38 sites were visited, out of which 34 were on the open sea coast and 4 were on upstream river bank & lake, where tsunami effect was reported to have reached. The information about the sites visited is presented in Table 1 and locations are shown in Figure 2. These sites were selected after taking into consideration: (i) varied near shore bathymetry, (ii) availability of dependable inundation evidences and (iii) reported varied tsunami effect. The locations of the sites are presented in the background of hydrographic chart (Fig. 3-1 to 3-7) for the further perception with respect to coastal geometry.

1.4 General tsunami information in brief:

A tsunami is a series of ocean waves generated (Anonymous, 2001) by sudden displacement of large volumes of water due to:

- i) The vertical movement of the sea floor as a result of large thrust type submarine earthquakes,
- ii) Submarine volcanic eruptions,
- iii) Meteor impacts, or
- iv) Coastal (land-based or submarine) landslides.

Tsunamis usually occur in the zones of strong seismic activity. Tsunamis travel outward in all directions from the source area and can strike coastal areas with devastating effect even in areas far removed from the source. Their speed depends on the depth of water. In deep and open ocean, waves can reach speeds of 800 kilometers per hour (approximately as fast as a commercial jetliner). The height of the waves in deep water may range from 30 to 60 centimeters, producing only a gentle rise and fall of the sea surface, and are usually unnoticed. As tsunami enter the shallow waters, the speed decreases rapidly. This causes the front of the wave to slow down relative to the back, producing a greater height as the water piles up onto the coastline. The configuration of the coastline, shape of the ocean floor, and characteristics of the advancing waves play an important role in the destructiveness of the wave. A wave may be of negligible size at one point on a coast and of much larger size at other points. Narrow bays and inlets may cause funneling effects that magnify the initial and subsequent waves. A tsunami may contain numerous waves, which may continue to arrive for hours after the first wave.

The first visible indication of an approaching tsunami may be the rapid retreat of the ocean. In some instances, particularly with local tsunamis, the water may initially rise. Tsunamis attack the coast either as a cresting wave, a fast rising tide, or bore. At some locations, the advancing turbulent front will be the most destructive part of the wave. In other situations, the greatest damage will be caused by the outflow of water back to the sea between tsunami surges, sweeping all before it and undermining roads, buildings and other works. Ships, boats, etc. unless moved away from shore, may be dashed against breakwaters, wharves and other craft, or be washed ashore and left grounded after the withdrawal of the seawater.

A tsunami also has considerable energy or momentum as it arrives at a shoreline. If the shoreline is a cliff, the wave will just reflect and go back in to sea. However, in the normal gradient coast the tsunami's momentum can carry it

considerable distance inland before its rise against gravity takes its energy and it must flow back to the sea. This distance can be very large if the coastal area is low and flat.

The 'height', 'run-up' and 'inundation' of the tsunami are some key parameters used for defining the potential seriousness of the tsunami event in a location (Anonymous, 2001). The tsunami 'height', or amplitude, at any point is the excess height of the tsunami over the normal sea level as it passes that point. The 'inundation' is the maximum horizontal landward (Figure 4) penetration, or intrusion of the tsunami from the shoreline. The 'run-up' is defined (Kaitoku, 2002) either as the; (i) difference between the elevation of maximum tsunami penetration (inundation line) and the sea-level at the time of the tsunami attack, or, as the (ii) elevation reached by seawater measured relative to some stated datum such as mean sea level, mean low water, sea level at the time of the tsunami attack. In practice, seldom can the height of each tsunami pulse be recorded unless there is a suitable tide gauge functioning in the area, whereas the 'run-up', 'height' and inundation parameters can be measured from various evidences during post tsunami surveys.

Section –2

STUDY APPROACH AND METHODOLOGY

The main study approach and methodology were formulated based on the post-tsunami survey field guide prepared by UNESCO (IOC, 1998). All the timings referred in this report are in Indian Standard Time (IST).

2.1 Run-up / inundation transects

In the sites visited, distinct tsunami high water marks were observed on walls and structures (Plate 1). At places levels of seaweed or debris caught in screens, upper branches of trees or other structures, provided indications of water level. These high water level marks were followed landward to identify maximum inundation limit. In uninhabited areas lines of landward limit of sea grass, debris, sediment, or floating garbage deposition provided indication of maximum inundation limit. At places, where no clear evidence was found for maximum inundation, the positions pointed out by local inhabitants, who saw the tsunami inundation was accepted after ascertaining reasonableness of such information. After identifying the maximum inundation limit and tsunami high water marks in a site, cross-sectional profiles with reference to local water level at the time of survey were taken from water line till the maximum inundation limit. Automatic survey leveling equipment and a graduated staff were used to record the levels. Generally leveling measurements were taken at an interval of 5m. Larger intervals were considered where the beach is flat and smaller intervals were considered where beach is highly undulating with features like dunes, ridges, valleys, etc. Wherever the inundation limit was accessible and the terrain is amicable for survey the profiles were continued till the inundation limit otherwise it was terminated at the last accessible point and only the position of the inundation limit was noted. Positions were noted at the beginning and end of

each cross-sectional profile using a portable GPS receiver (Magellan Nav 5000 DLX).

After returning from the field, these measured levels were reduced to the Chart Datum that was approximately arrived from the time of observation of the water line and the corresponding predicted-tide of the location. The predicted-tide for different locations was arrived by linear interpolation/ extrapolation of tides at Nagapattinam and Chennai, the nearby tidal stations in the study region.

During the course of field work additional upstream riverbank sites were also visited along few river courses to document the eventual propagation of tsunami bores upstream in those estuaries.

2.2 Structural damage documentation

Intensity of damages to various types of structures due to momentum of tsunami waves are generally controlled by a number of factors associated with the structures such as proximity to the sea, dimension, shape, orientation, surface area subjected to the waves, material of construction, quality of construction, age of the structure, ground level at the site of the structure, foundation soil, drainage pattern around the structure, natural or artificial barriers or protection between the sea and the structure, proximity to berthing of marine vessels and roads vehicular traffic.

In the sites visited, typical tsunamigenic structural damages were inspected with an aim to understand the reasons of structural failure. Attempts were also made to understand the reason why some structures remained unaffected as compared to nearby damaged structures. Sample feature characteristics were documented through field notes and photography. The natural barriers which

appeared to have sobered the tsunami impacts at different sites were identified and their characteristics were noted.

2.3 Interviewing tsunami survivor / eyewitness

At each site, oral interviews were carried out with the tsunami survivor or eyewitness (Plate 4). Communicating with those interviewees was very effective as many of survey team members had the same mother tongue as the inhabitants of the surveyed sites. The eyewitness/survivors and also collective community response were documented regarding the times of arrival of tsunami, its nature at the time of arrival and other anomalous experience related to the tsunami. These interview responses were in local language, but they were immediately noted down in English with as much detail as possible.

2.4 Sampling tsunami transported sediments

At each site, sediment samples were collected with various criteria. Wherever confidently identifiable post tsunami deposit could be located, pits were dug and sample of entire post tsunami section were collected as bulk sample at every 5 cm interval. At few places core samples were also collected in acrylic liners. Before taking samples, photographs of the pit section were taken, thickness of the post tsunami deposit was measured and position of the sampling location was determined with a portable GPS. Surface sediment samples were also collected along inundation cross section transects. These surface samples were obtained with a graduated transparent acrylic core liner (63 mm diameter) and kept in properly labeled polythene packets after visually characterizing the collected samples. Along transects, samples were collected at closer interval from shoreline to dune areas, and afterwards the spacing was increased. At few places locations of sampling along transects could be determined with GPS, otherwise their locations were recorded in terms of distance in meters from the beginning point of the transect near shoreline. Samples of anomalous tsunami

surface deposits (mud balls, black sands, beach rocks and fossil lag deposits) were also collected from few sites. Tsunami deposits were identified on the basis of their disposition over a pre-tsunami base. The pre-tsunami bases were identified by digging trenches through tsunami deposit till the level of underlying dead or dying grass (Plate 3) or paddy roots/ surfaces of metal roads or floors of tsunami damaged buildings/anthropogenic materials such as plastic/rotten vegetation etc.

2.5 Littoral environmental observation (LEO)

Breaking wave parameters and the littoral environmental observations were made at each site. Breaking wave height, wave period and direction were observed during the study period. Heights of 10 consecutive breaking waves (breakers) were visually observed and the average of those heights was noted as the corresponding breaking wave height. Simultaneously, the total time elapsed beginning with the first breaker till the eleventh was averaged and recorded as the corresponding breaker period. The wave direction was visually observed and the approximate values are recorded. Longshore current velocity, surf zone width, wind speed and direction were the other parameters observed. Neutrally buoyant floats were released in the surf zone and the distance traveled by them in 2 minutes and the direction of travel was noted. The speed and direction of these floats were noted as the longshore current speed and direction. Surf zone width was visually estimated. Wind speed was observed based on the intensity and noted as calm, mild, moderate, medium, strong or very strong which are assumed as 0, 5, 10, 20, 40, or 60 km/h respectively and the direction was observed with the help of a magnetic compass. At each site, beach surface sediment samples were collected from the inter-tidal region close to the water line. These samples were collected for inferring prevailing wave climate through grain size distribution pattern. The grain size distribution pattern was determined later in the laboratory by sieve analysis procedure.

2.6 Surface sea water quality analysis

The seawater samples were collected at different locations (Table 5) for measuring dissolved oxygen, phosphate-phosphorus and Silicate-silicon in the surface sea water. In field, the seawater samples were collected from the shoreline region. At each station two samples were collected. Samples for estimation of dissolved oxygen were collected in glass bottles and analysed in the field following the Winkler's Method (Grasshoff et al. 1983). Samples for nutrients were collected in the plastic bottles and were transported to the shore laboratory for analysis. In laboratory the nutrients were analysed using SKALAR Auto Analyser.

2.7 Tsunami approach directions

The directions of approach of tsunami at the beach were inferred from the directions of fallen trees (Plate 2), walls, poles, geometry of scour, etc.

Section – 3

RESULTS AND OBSERVATIONS

3.1 Tsunami inundation limit, run-up and bearing

The inundation limits and the run-up height (corresponding to the Chart Datum) observed in this study are presented in Table 2. Presentation of observed tsunami inundation limits at various sites is shown as map (Fig. 6) and as bar graph (Fig. 7). Presentation of observed tsunami run-up heights at various sites is shown as map (Fig. 8) and as bar graph (Fig. 9). This report presents the summary of run-up and inundation measurements. Detailed information about these aspects is presented as a separate report (NIO, 2005). More than 25 locations were surveyed to assess the inundation limits as well as run-up heights. At most of the locations more than one cross section profile was considered to ascertain the inundation and run-up height values. These cross sectional profiles at various sites are presented in Figs. 5-1 to 5-13. The inundation limit varied between 31 m and 862 m at Kottaikadu Kuppam and at Nagore (along mid-profiles) respectively. The run-up height varied between 2.20 m and 6.54 m at Krishnapatnam and Periyakalpet (North) respectively. Inferences about direction of approach of tsunami at different sites are presented in Table 3 and Fig. 10.

3.2 Tsunamigenic structural failures and other damages

Intensity of damages to various types of structures due to of tsunami waves is generally controlled by number factors associated with the structures such as:

- a) Proximity to the sea
- b) Dimension
- c) Shape

- d) Orientation of the structure with respect to tsunami wave direction
- e) Surface area subjected to the waves
- f) Degree of transparency of the structure to the flow of water
- g) Material of construction
- h) Quality of construction
- i) Age of the structure
- j) Ground level at the site of the structure
- k) Foundation soil condition
- l) Drainage pattern around the structure
- m) Natural or artificial barriers between the sea and the structure
- n) Proximity to the berthing of marine vessels and other land vehicles.

The factors which have played major role in the failures of coastal settlement and other functional structures along the south eastern coast of India during the tsunami generated by the M9 earthquake are:

- Proximity to the sea
- Poor planning
- Inappropriate and inferior materials
- Poor quality of construction and
- Inappropriate foundation designs

Majority of the people living near the coast in the coastal districts of Tamilnadu are fishermen with houses made of poor quality construction materials such as mud plasters, thatched roof, improper ratios of materials in the concrete, etc. On the beach, many cemented houses/structures even with good construction materials suffered foundation failure lead by scour due to excessive and high velocity flow around them. The progressive scour around and below shallow foundations leads to tilt of the structure and the structure fails due to eccentric loading.

Total failure of structures with load bearing walls appears to have initiated by the failure of walls followed by the collapse of roof. In spite of good quality construction with appropriate materials, structures like compound wall, short walls of sheds, etc., have failed at some locations because they are not designed for such impact loads (Plate 5). Following are some examples of structural failures and associated factors as observed during this survey.

i) Proximity to the sea:

Houses/structures in the first row facing the sea seem to have failed primarily by the impact force of the tsunami waves and secondarily by scour due to rapidly moving tsunami waters (Plates 6 - 9). In some places the front row of houses were built over elevated ground consisting of silty sands (Plates 10 & 11). The tsunami waves caused heavy erosion of those ground and washed away the structures built over it. In some locations, the impact forces are believed to have been so powerful that even concrete pillars and steel structures could not withstand (Plates 12 & 13).

ii) Dimension:

When compared to smaller and isolated structures stability is more in bigger structures due to structural integrity through more internal and external structural components in the lateral directions. The stability of a structure is more if the increase of structural dimension in the direction of the flow is more than that in the direction perpendicular to the flow. Instances of structural failures due to these effects were found at several locations (Plate 14).

iii) Shape:

Structures with curved surface, particularly circular in plan, withstood the thrust of the tsunami flow. For example, at Nagapattinam harbour (Plate 15) the cylindrical

oil storage tank (in the background), which is bigger than the generator room (in the right side foreground), escaped from failure due to tsunami flow. The same way the cylindrical light house structure at Nagapattinam harbour could survive the tsunami attack (Plate 16).

iv) Orientation and surface area facing the tsunami waves:

Orientation of the structure should be such that the surface area subject to the direct wave attack is minimal. Hence the least lateral dimension of the structure should be perpendicular to the direction the waves' attack. Deviation from this general constructional concept has caused failures (Plate 4). In the photo, houses (seen extreme left and extreme right) having least lateral dimensions to the flow direction have withstood the impact while those which had larger lateral dimensions (closer to the power transmission pole), failed.

v) Degree of transparency of the structure to the flow of water:

Certain functional structures such as office buildings of port/harbor, customs, fisheries and other navigation related office buildings need to be always closer to waterfront. Such concrete structures very near to sea made transparent to certain degree by stilt construction with sufficiently deeper column foundations could withstand flow of tsunami waters. For example the Plate 17 shows such a structure which is right on the beach and survived the tsunami attack.

vi) Material and quality of construction:

In many locations mud plasters were used for binding the burnt bricks in the walls (Plate 18) and hence walls collapsed by inundation waters of tsunami. It has been noticed, that structures at many locations were of poor quality due to non-engineered construction practices. Even many damaged houses with concrete

structural members were found to have been built by local people without appropriate engineering planning, design and supervision (Plate 19).

vii) Age of structures:

Age old structures are always vulnerable to failure even to small increment of load. Plate 20 shows such an old road bridge made of bricks with lime mortar at Karaikal, where one of the piers got detached from the superstructure due to extensive scour lead settlement and impact of tsunami surges.

viii) Ground level at the site of the structure:

Structures over appropriately elevated ground level with respect to tsunami inundation are safer. Existing density of population in the coastal areas forces people to utilize even low lying lands for the settlement. In such cases, in addition to impact force of tsunami flow, presence of stagnant water for a longer duration can cause foundation related failures. Plate 21 shows such a condition in which a house is being constructed at a low lying area but built over artificially elevated ground so that plinth level is well above inundation level. Plate 22 shows two structures, one on a higher elevation (right) and the other on the lower ground level (left). It was observed that due to longer submergence of foundation in the stagnant water and local scour, the left side cemented structure has failed.

ix) Foundation soil condition:

Type of soil available at the site for the foundation plays an important role in the stability of foundation. Loose sandy soil is vulnerable with respect to erosion/scour. Soft clayey soil leads to settlement failure of the structure on longer exposure to inundated waters. Such instances of foundation failure due to erosion of loose sandy soil by tsunami flow were found at places (Plate 23).

x) Drainage pattern around the structure:

Structures in the low lying area can be subjected to severe and complex flow conditions around them causing failure. For example, some structures (Plate 22) at Velankanni, Nagappattinam and Nagore which were considerably away from the sea were affected by lateral tsunami flow through nearby creeks and streams and had foundation failure due to severe and complex flow around them.

xi) Natural or artificial barriers between the sea and the structure:

There are many natural and artificial coastal features such as sand dunes, dense coastal vegetations, break-waters, seawall, etc., which were found to have played considerable role in diffusing down high energy of tsunami waves. Due to dense mangroves in the Pichavaram, adjacent hinterland villages have escaped from inundation and damages. Plate 24 shows the intertwined stems of the mangroves plants at Pitchavaram which appear to have retarded the tsunami flow. Plate 2 shows absorption of tsunami wave energy by frontal rows of casuarinas trees. Plate 25 shows rubble mound seawall at Tarangambadi which has considerably reduced the tsunami wave impact over the structures seen behind it. In the same way structures along marine drive were protected due to dissipation of tsunami wave energy by the rubble-mound seawall.

xii) Proximity to the berthing of marine vessels and other land vehicles:

Uplifted boats, or similar floating marine vessels and washed away motor vehicles on land cause damages to nearby structures by direct collision. The structures close to port/jetty and coastal road networks and vehicular parking area are vulnerable to such damages. Plate 26 shows the uplifted fishing vessels taken much interior on land side by tsunami which caused heavy damages to the nearby structures.

3.3 Eyewitness account and other observations

3.3.1 Site: **VEDARANYAM** (Fig. 3-7, Site ID: 1, visited on 21/01/05)

- i) On reaching Vedaranyam beach it was observed that tsunami created breaches in the beach approach road. These breaches as well other canal like water bodies have made the beach inaccessible. However southward of the beach approach road, a vast field was noticed which appeared to have been covered by tsunami derived sandy deposit. Local people confirmed that this field was a cricket ground for village boys. In this field few pits were dug to look for pre-tsunami grass covered ground level and on finding such places, sediment samples were collected. In this field large number of elliptical shaped mud balls (~30 cm length, ~12 cm diameter) were found to lie strewn on the sandy tsunami deposit surface. Scoured zones surround these mud balls, and there appears to be a general pattern of leeward side (pointing shoreward i.e. SSW) of these scouring. It was observed that the pre-tsunami ground sediments (as seen in the erosional side cuttings (recent) of canals as well in fresh section cut by us) were of black clayey type, whereas some of the mud balls were black, while others were brownish (or olive green).

- ii) Here the villagers reported only one death of a person who went to the beach for the cremation rituals of his dead family member. We were told that police came and asked the villagers to vacate the village because huge waves were coming. We did not believe it, because we could not understand how police got this indication of approaching tsunami in advance. So we went to police station to enquire about this aspect. We were informed that the police in this station keep their wireless sets always on. On 26/12/2004 morning they overheard a message from Kollidam police that huge waves hit nearby coast. After some time, they overheard a message from Nagapattinam police, that huge waves hit Nagapattinam. With this second message, the local police sensed some danger from the sea and using microphone advised the people

in coastal areas of Vedaranyam to vacate seashore immediately. It was this remarkable alertness of local policemen that many lives were saved in this area.

- iii) We were also told that on 26/12/2004 (i.e. tsunami day) around 7.00 am people noticed about 1 – 2 feet oscillation of water level in local ponds.

3.3.2 **ARUKATTUTHURAI** (Fig. 3-7, Site ID: 2, visited on 21/01/05)

- i) Arukattuthurai beach is situated north of Vedaranyam. We met one tsunami surviving fisherman Mr.Thambi Rajan, who was carried away by about 500m landward from where he was sitting on the beach and repairing his net. He heard some murmuring sound before arrival of tsunami, but did not pay much attention even though he had not heard similar sound earlier. He thought the sound would go away. According to him the arrival of tsunami in the shoreline was sudden and it looked like a muddy coloured sea water wall. While he was being carried away by tsunami, the net he was repairing got wrapped around his neck and the trailing of the net was getting intermittently stuck in the trees.
- ii) Another surviving fisherman Mr.Ramdoss said that he could run away to the village but the tsunami water was chasing him about 10 feet behind. He didn't notice any withdrawal of water.
- iii) We saw a big boat [height 2.8m, length10.2m, breadth 3.3m, draught 1.6m] near a thatched house inside the village. We were told that this boat have been lifted by tsunami from its location on the beach near waterline, where it was kept for repair. The position of the boat was about 200m from the waterline.

- iv) People said that on tsunami day, before arrival of tsunami the sea was very calm and there was not much wind.
- v) People also said that the beach has now become somewhat narrower than pre-tsunami days.

3.3.3 Site: **SERUDHUR** (Fig. 3-6, Site ID: 3, visited on 18/01/05)

- i) The Serudhur village is located south of Velankanni creek. We interviewed a tsunami surviving fisherman Mr. Govindaswamy (Age: 75 years) of this village. On 26 /12/2004, at the time arrival of tsunami at this site, he was sitting on the beach at a location about 50 m from the shoreline. According to him:
 - a) The first tsunami arrived at this beach around 09:15 hrs. He estimated this time based on the fact that the first tsunami arrived at this site a little later than 09:00 hrs, when people assemble here for buying fish.
 - b) Prior to arrival of tsunami there was some sound like an airplane or a helicopter.
 - c) The approaching tsunami was noticed by him as a frighteningly huge wave of black muddy water about a kilometer from the shore. On seeing that huge wave, he got afraid and ran towards village high ground. He had already reached the village high ground when the wave hit him and he was thrown southwards. He could not observe anything further about tsunami as he ran towards village as soon as he managed to stand and at that time the water was at his chest level (1.2 m).

- ii) According to other villagers:
 - a) The up-rush and backrush of the first tsunami was over within about 10 minutes.
 - b) The people on the beach, who were busy in selling fish and were not looking towards sea, did not pay attention to that airplane or helicopter like sound which was heard a little before arrival of tsunami. Probably, that was because they did not feel this sound as anything abnormal, as they have heard such sound in the past when the airplanes pass at distance.
- iii) It was noticed that the brick wall of a hut on the seaward end of the village high ground was damaged by tsunami, whereas the thatched roofs of the nearby houses were not damaged. Even the houses in the village as such were not damaged. It appears that weak foundation may be the reason for damage in some houses or boundary walls.
- iv) Based on villagers report as well the evidence of exposed pipes of a hand pump, it appears that about 10 meters wide and 1.5 m high village ground, in the areas southwards of Velankanni Creek, was eroded by tsunami action.

3.3.4 Site: **VELANKANNI** (Fig. 3-6, Site ID: 4, visited on 18/01/05)

- i) According to a tsunami eyewitness Mr. Tamil Selvam, the first tsunami arrived in this area around 09:20 hrs. Mr. Tamil Selvam ran towards safety after seeing the first tsunami and came back later to look for his brother who had shop in the beach. Mr Selvam thinks a second tsunami came in this place around 10:45 hrs and a third wave around 15:30 hrs, however he was not sure of this later timings. The last tsunami had very less speed.

- ii) On enquiry, the local fishermen informed that they did not notice any change in the type of fish catch between pre and post tsunami days. However in the post-tsunami period the quantity of catch have been reduced.
- iii) It was observed that the shops destroyed by tsunami in the Velankanni beach area were mostly located within about 10 meters from the shoreline.
- iv) In the northern part of the Velankanni beach there is a coconut grove, which was not damaged by tsunami. According to local people, there was a sparsely shrub covered raised ground between this coconut grove and a raised village ground located about 200 m southwards of the grove. That sparsely shrub covered raised ground was totally eroded by tsunami and the tar covered road (located about 200 m landward from the shoreline) on this raised ground was breached causing formation of a canal like feature.

3.3.5 Site: **SAMANTHANPETTAI** (Fig. 3-6, Site ID: 5, visited on 20/01/05)

- i) The interviewee, Mr. C. Jayapal, a tsunami surviving fisherman of this village was sitting (facing the sea) on the beach at the time of arrival of tsunami at this site and was carried away by tsunami landward. According to him:
 - a) Before the arrival of tsunami, there was nothing abnormal in the situation of sea or weather. However, there was some sound like a helicopter flying / train passing far away.
 - b) The first tsunami arrived at this beach around 09:15 hrs. Mr. Jayapal feels this timing is correct because it is based on his wristwatch, which he was wearing on that day as usual.
 - c) Just before the tsunami's arrival, the sea withdrew by about 100 meters from the shoreline.

- ii) The approximate location, where Mr. C. Jayapal was sitting on the beach is Lat 10° 48.70' N, Lon 79° 51.41' E and from that point, the bearing of the location where he was carried away (towards Nagapattinam collector's office) by tsunami is about 240°.
- iii) Several villagers present in the beach, informed about many survivors who were carried away inland by tsunami. While being carried away, those people tried to catch whatever tree/pole they could hold and hence received bruises / scratches on their body. Further they also informed that there was a total of three tsunami waves arrived at this site. The second one arrived about half an hour after the first. The water of the first tsunami did not cause much damage but had much backwash. Whereas, the second tsunami which caused most of the damages did not have much backwash. There was a third tsunami, but it was much weaker as compared to the first two.
- iv) During visit to this site, a herd of cows were on the beach in a place, which is about 30 – 40 meters landward of the breaker zone. We reached this place around 08:45 AM, which incidentally happens to be close to the tsunami arrival time in this area, we wanted to know the fate of those cows which were sitting on the beach on the tsunami day. On enquiry, one fisherman told us that the village cattle usually sit there from morning till about 10:00 AM every day. Surprisingly, on tsunami day most of the cows left that place around 08:00 AM and went towards the distant palm tree line located about 1 km landward from the beach. The villagers even told that a solitary cow, which strayed towards the breaker zone about 15 minutes before the arrival of tsunami, suddenly started running away from the beach. At that time the fishermen did not take note of this peculiar behaviour of the cattle. But in retrospect they now feel that those cattle perhaps sensed something dangerous from the sea about an hour before and started moving inland. The result was that, except one goat, which was kept tied in the village, none of the cattle perished due to tsunami.

- v) The fishermen informed that they do not see any change in the type of beach sediments due to tsunami and the black sand presently seen on the beach were present even before tsunami. They also informed about 'no change' in the type of fish catch between pre and post tsunami days.

- vi) We noticed a casuarinas grove slightly northward of the village on a dune. It was observed that the number of trees in the 5 - 10 meters wide seaward front this grove, lie flattened after being twisted at the bottom of their trunk. Some of these trees were found to be partially alive (as evidenced by green leaves at places) and interestingly almost all the trees are lying on the ground oriented broadly in same direction (i.e 240°). The flattening of these casuarinas trees appear to have been caused by recent tsunami and the general orientation of the fallen trees suggest a direction of tsunami water flow from NE to SW.

3.3.6 Site: **NAGORE** (Fig. 3-6, Site ID: 6, visited on 19/01/05)

- i) In this site no tsunami survivor / eyewitness could be interviewed as most of the survivors were staying in the relief camps. Whatever information could be gathered are from the curious locals who came to see us working in the beach. These local people appeared to be educated and stay about 1.0 – 1.5 km landward from the beach and they have not witnessed the tsunami arrival on the beach. However according to them;
 - a) The first tsunami hit the village around 09:05 hrs and it inundated only up to the village road end. The second one came around 09:15 and inundated further inland, perhaps up to the railway level crossing.

- b) There were many houses/huts on both sides of the beach approach road behind the children's park. However all those houses have been destroyed by tsunami and about 450 persons were died.
 - c) Immediately after the first tsunami hit this area, many people from inner part of the village came running to rescue people from the beach side village. However they ran away as the second wave came rushing. At that time the sea surface was like a black wall.
-
- ii) In the children's park area presence of little grasses could be seen, which perhaps suggests no significant deposition in this area.
 - iii) The houses (huts as well masonry structures) which were facing the open beach got destroyed, whereas damage was considerable less to the structures located behind the casuarinas / coconut groves.
 - iv) Some of the concrete structures (eg. Base of the swing and parallel bar in the children's park) were uprooted, whereas nearby small shrubs remained intact. It appears that the concrete structures were uprooted due to shallow foundation on sandy ground.
 - v) The beach approach road was eroded heavily.
 - vi) People taking bath around 06:00 hrs on 26 Dec'04 in the Nagore Darga Tank, observed waves in the tank water.
 - vii) All the cattle of the beach side village came back only after the tsunami episode was over. Perhaps they sensed something dangerous from the sea and went inland well before the arrival of tsunami.

3.3.7 Site: **ARASALARU RIVER BARRAGE** (Fig. 3-6, Site ID: 7, visited on 22/01/05)

On the way to Karaikal we had to cross the Arasalaru River. We were informed by local people that tsunami bore traveled upstream along this river and reached up to the barrage gate. We went to the barrage and from distinct mark found that the tsunami water level at the barrage gate was about 1.7m. No tsunami deposit could be found over the brick lined sloping sides of the banks of this river.

3.3.8 Site: **KARAIKAL** (Fig. 3-6, Site ID: 8, visited on 22/01/05)

- i) It appears that the tsunami water level was ~2m near Karaikal lighthouse.
- ii) The orientation of fallen trees near this lighthouse also was $\sim 260^{\circ}$.
- iii) There are large tracts shoreward where post-tsunami sediment ($\sim 15\text{cm}$) is topped by thin layer of black sand.
- iv) According to local people, water reached up to about Cauvery Public School building (location of maximum inundation point is $10^{\circ} 54.981'$, $79^{\circ} 50.458'$) in Thomas Arul Street.
- v) Sediment samples, resembled tsunami deposit, were collected from the marshy land and a close by roadside depression [$10^{\circ} 54.995'\text{N}$, $79^{\circ} 50.533'\text{E}$] behind IMD Office.
- vi) In Karaikal city, a photography shop displayed large number of tsunami related photographs. On enquiry it was revealed that the enthusiastic owner of the shop went around Karaikal area immediately after the first tsunami hit this area and could photograph the approaching second tsunami and inundation in this area. The photographer provided us many of those extremely important photographs, which recorded the character of the tsunami arrival in this site.

3.3.9 Site: **TARANGAMBADI** (Fig. 3-6, Site ID: 9, visited on 24/01/05)

- i) We met some fishermen who were fishing out in the sea at the time of tsunami, in the areas of about 30 m water depth (~20 km offshore). According to them, as such nothing unusual was noticed in the sea at that time. However they observed that many of their fishing lines got entangled. Usually 400 - 500 fishing lines are lowered at a time, and they do not get entangled. So the entanglement of lines on the tsunami day now appears to them as something unusual.
- ii) We met one tsunami survivor, Mr. M. Sekhar (35 years), who was fishing from a sea side wall of a dilapidated old seashore structure. He noticed the tsunami as a sudden rise of muddy sea water of about twice the height of the wall at a distance of about 25 m offshore. Tsunami hit him and he was thrown near the wall of a far away building (location 11°01.512 N; 79°51.415' E). The direction of his drift was measured to be 285°. Water was at his chest level, when he could stand on the ground. Immediately he started climbing the building, and the second wave came as he was climbing. He didn't observe any third wave.
- iii) The villagers informed that the black sand presently seen on the beach were present even before tsunami. They did not notice any change in the between pre and post tsunami days, only the shoreline appears to have advanced shoreward a little.
- iv) Again here we noticed a heard of cattle sitting in the beach. Fishermen told that those cattle went shoreward well before the tsunami arrived at this place. Nowadays the fisherman started watching for the anomalous behaviour of those cows as a possible warning of danger arriving from the sea.

- v) Arun, a young boy, showed us a water tank [location 11°01.831'N; 79°50.711' E] in Pudupettai village southwest of Tarangampadi. He said that on seeing approaching tsunami water, he also ran up like many other villagers to the water tank and climbed the stairs. According to him the water near the tank was at ground level and the water which was grazing the road flooded the adjacent low lying field further westward.

- vi) Fallen trees facing the open sea between the dunes suggested east to west flow direction of tsunami in this area.

- vii) We visited nearby PPN power plant jetty, where we were informed that the containers lying in the jetty were lifted by tsunami and brought landward by about 50m. The drift direction of the container was about 255°. Near the jetty water depth has been increased. Many stone blocks put along the offshore pipeline were brought onshore.

- viii) According to eyewitnesses, the seawater has surely receded in the PPN jetty area during tsunami as people could notice many of collars of manholes of the intake water pipe, which always remain submerged.

- ix) Further, as inferred by plant officials, based on the unusual sump level alarm in the plant, the tsunami appears to have struck at least three times in the PPN jetty area. The first one was at 09:07 Hrs, the second one at 10:09 Hrs and a third one by 10:50 Hrs.

3.3.10 Site: **MELAIYUR BRIDGE** (Fig. 3-6, Site ID: 10, visited on 25/01/05)

- i) The Melaiyur bridge (location: 11°08.728' N; 79°49.147' E) is a bamboo bridge over Cauvery. Tsunami bore appears to have reached this place along the river as the villagers told that the bodies of tsunami victims got stuck in this

bridge. Those victims were pilgrims from Karnataka, who were taking bath at the confluence of Cauvery river with the sea. We saw normal high tide water pass the bridge. It was interesting to note that a simple bamboo bridge withstood the impact of tsunami bore in this place.

- ii) The bridge (location: 11°08.407' N; 79°50.376' E) near Keezhaperumpallam village, as told by villagers, was the last road bridge over river Cauvery. According to the villagers, tsunami water reached up to here into the paddy fields. Water could not penetrate further over land areas due to the high barrier of the road. However, along the river the tsunami bore passed under the bridge and proceeded upstream at least up to the Melayur regulator. Farmers showed the dead paddy crops in the field which died due to the saline water intrusion. Soil sample collected from the paddy fields showed clay layers on the top of sands.

3.3.11 Site: **POOMPUHAR** (Fig. 3-6, Site ID: 11, visited on 25/01/05)

i) The following information was provided by tsunami surviving fishermen, Mr. N. Veerappan (20 years), Mr. V. Madhi (21 years) and Mr. T. Poonthamizhan (18 Years). These persons were mending their nets at the time of arrival of tsunami.

a) Prior to arrival of tsunami the wind was calm, the sea was as normal as usual.

b) All of a sudden they saw their boat, kept on the beach, was just lifted up by raised seawater, which they consider to be the first tsunami. The time was ~08.45 AM. They wanted to catch the boat, but, the big second wave had come immediately. These people were thrown onshore. Mr. Veerappan was thrown away near the bus stand.

- c) These people, after being dropped on the ground, came running to the beach to see what happened to their colleagues. At that time they appear to have seen the sea receded by about 500 m and then came the third big wave. The third big wave appears to be much less powerful and penetrated landward by only about 500 m.
- d) The sea water was of normal colour, no foam, no sound in advance and it became muddy after reaching land.
- e) After the first wave wives of the fishermen fishing offshore came to the seashore to find the fate of their husbands etc., and those ladies were the ones who died due to the second wave.
- f) Fishermen, who were in the sea at the time of tsunami, were not affected. Fishermen fishing with lines from fishing boats anchored offshore at about 18 m water depth, observed spiraling motion of the anchor and also some anchors were lifted. They didn't observe any tangling of hooks. The nets which were placed at about 15 m depth area appear to have moved shoreward to the areas of 10 m water depth.
- g) Most of the ladies in the village died because their hair got entangled in the thorny bushes. They saw that dead people had foam in their mouth.

ii) Villagers showed a paddy field where tsunami water reached by the side of a mud embankment (bund) of a paddy field. Height of the water level at this location was measured to be ~1.10 m. The bund height was 2.0 - 2.5 m and the top width was 5.5 m with 45° slope shoreward. If this bund was not there, then salt water could have gone still landward and inundated more paddy fields.

iii) The location of the bund (11°08.535' N; 79°51.454' E) and the present location of a catamaran (11°08.521' N; 79°50.963' E) brought onshore appear to suggest extent of inundation.

iv) Near the confluence of the Cauvery River, on its northern bank (11° 08.254' N; 79° 51.276' E), tsunami water level appears to have been ~3.5 m higher than the water level of the river at the time (25/1/05, 13:20 hrs) of our visit. This height was estimated based on the garbage and sea grass stuck on the branch of a tree on the bank.

v) The Cauvery River is very narrow and shallower over here. From the fishermen working on the riverbed, it appears that the water is just chest deep over here. About 15 cm of post tsunami sand deposit overlying over grass roots were found at one location. Numerous elliptical clay lumps, were found lying near this location over the sandy (black) surface. However those clay lumps were much smaller compared to those seen at Vedaranyam.

3.3.12 Site: **THIRUMULLAI VASSAL** (Fig. 3-6, Site ID: 12, visited on 2/01/05)

i) Like other sites, the Thirumullaivassal village also has a straight approach road to beach. A tsunami eyewitness Mr. P Murugan (27 years) told that at the time of arrival of tsunami in this place, he was sitting on a culvert wall by the side of this beach approach road. Suddenly, a teashop owner Mr. Mani, (whose shop is about 20 m further landward of the place where Mr. Murugan was sitting) shouted that a dangerous looking wave is coming from the sea. Hearing this , Mr. Murugan looked towards the sea and on seeing the approaching dangerous looking wave, he also started running.

ii) Another tsunami eyewitness Mr. V. Arumugan (48 years) said that, he saw boats and cows floating in water at about lamp post high level. The sound was

something like when strong wind enters a narrow passage (whee-whee). The water of the tsunami was like black coloured wall, which was rolling at the top levels. According to him the survivors who were carried away by tsunami water felt like wave riding.

Other assorted responses of a group of villagers were as follows:

- a) There were three tsunami waves at this site and their timings of arrival were 8.45 hrs, 8.50 Hrs and 8.55 hrs respectively). The first wave penetrated maximum landward and the penetration of the last one was the least. Tsunami water receded at this site in the same speed as it rose.
- b) Almost all the dead bodies were left towards the shoreward end of the tsunami inundation.
- c) All the dead people had foam in their mouth and eyes were muddy. Around Sirkazhi area, people saw bubble coming in the ponds on tsunami day around 06.50 AM.
- d) Cattle, which were not tied, fled the village well before tsunami.
- e) While many trees died due to tsunami water inundation, we saw a road side tree, which survived despite being submerged under tsunami seawater. Villagers told that this tree ('Punga maram'- in Tamil) was recommended by the red cross people to be planted as it can withstand saline water.

3.3.13 THODUVAI (Fig. 3-5, Site ID: 13, visited on 26/01/05)

- i) Thoduvai village is about 3 Km north of Thirumullaivassal village. In the beach it was observed that Casuarinas grove on the distant dunes remain more or

less intact. Even the coconut grove on the dune adjacent to village highland remained intact. Nearby houses in the villages, no tsunami high water mark could be observed.

- ii) The maximum inundation limit as shown by villagers along the beach approach road was found to be (11°16.336' N; 79°50.120' E).

3.3.14 COLEROON BRIDGE (Fig. 3-5, Site ID: 14, visited on 28/01/05)

- i) Coleroon bridge is a road bridge over Coleroon River, between Mayiladuthurai and Chidambaram along the national highway NH45A). The position of the northern end of the bridge is 11° 20.315' N, 79° 42.625' E.
- ii) The watchman of the bridge office, Mr. G. Balasubrahmanian, told that the distance of the sea from the bridge along the river course is about 12 Km. Mr. Balasubrahmanian maintains log of water level on the pillars of the railway bridge, which is located ~ 150 meters east of the Coleroon road bridge. According to him during the tsunami time there was some perceivable rise of water level in this area. On hearing about tsunami he measured the level more frequently and maintained the following log for a longer period;

26.12.04	09:40 hrs	2.5 feet	above normal level (which is zero)
	10:50 hrs	4.5 feet	above normal level
	20:50 hrs	3.5 feet	above normal level
	21:40 hrs	3.0 feet	above normal level
	22:35 hrs	4.25 feet	above normal level
	23:25 hrs	4.0 feet	above normal level
27.12.04	00:10 hrs	4.5 feet	above normal level
	01:20 hrs	4.0 feet	above normal level

3.3.15 KODIAMPALAYAM (Fig. 3-5, Site ID: 15, visited on 27/01/05)

- i) The broken bridge in the Kodiampalayam village was approached after traversing through several kilometers of narrow winding road through a swampy mangrove area. The mangrove plants were about 2 – 3 feet high. The broken bridge was connecting a small island like feature, eastern side of which is a beach. The villagers told that tsunami water nearly submerged the island and the water from the open sea came from east and the water wall, came from riverside which rushed through the stream like water body and submerged the mangrove swamp.
- ii) Clear tsunami watermark could be seen on the wall of the bus stand like structure (position 11°23.074' N; 79°48.60 E) near the broken bridge. Considering the level of the nearby rivulet flowing through the marshy mangrove covered [sparsely distributed] zone as sea level of tsunami time, leveling was done to mark the height of tsunami water mark on the bus stand like structure.
- iii) The rivulet was crossed by canoe to reach the open sea coast of the island. The boatman and the villagers on the canoe informed that as tsunami water entered the swamp and rivulet, it was like a reddish wall of water. The boat was at that time alongside the bus stand side jetty. On seeing the rushing water, the passengers and the boatman jumped on the jetty and ran shoreward. Later they found the boat on the swamp, in a place far southwards of the jetty.
- iv) On reaching the jetty on the western side of the island, it was found that several brick pillars [~ 1 ft *1 ft * 2 ft] of the southern side of the bridge were uprooted and thrown on the adjacent marshy land. These blocks were lying scattered about 15 m southward from the bridge. The compass reading of the

drift direction of these railing blocks suggest that the direction of tsunami water flow over here was from NE to SW.

- v) On the island, one eye witness Mr. G. Murugan informed that on tsunami day he got down from the boat after fishing and was proceeding towards village, while his 3 other colleagues were in the beach removing fish from the nets. When he reached near the MGR statue [position 11°23.012'N; 79°48.953' E], he heard a loud unusual noise coming from the seaside. On hearing that noise, he looked back and saw his boat is tumbling in water and rushing towards the village. Similarly he saw many villagers were also tumbling and coming along with the water. He and some others tried to stop his boat from tumbling but could not.
- vi) According to Mr. Murugan, tsunami water (muddy water with foam) was rushing like a wall and making sound like spilling of water around (kala – kala – kala). Before the tsunami, sea was like any other day, nothing unusual. There were three tsunami high water to enter the village. The first wave on the village road level was waist high. The second wave was also waist high. The third one, the highest, and entered maximum distance inside the village.
- vii) Mr. Murugan showed a large dune structure on the eastern side of the island. According to him this dune was a continuous huge structure on the eastern end of the village. Of course there was a gap of about 10 – 15 m wide in that dune, through which the villagers used to approach the beach. Now almost the entire northern part (i.e. dune part lying north of the gap) of the dune has been eroded by the tsunami.
- viii) It was observed that a number of casurinas trees have fallen on the ground. The compass reading of the fallen tree direction at several places

was observed to be around 255° (broken root end at NE and dead tree top end towards SW).

- ix) Along the beach approach un-tarred road, two small depressions (position 11°23.083' N; 79°49.131'E) were found with some water stagnating in them. One of the depressions contained iron oxide coloured water with deposit on its walls, while the other adjacent depression contained blackish water with decayed leaves.
- x) This island appeared to be least disturbed by post tsunami rehabilitation or by bulldozing activity. Since no bulldozers could come to the village due to the broken bridge (broken earlier than the tsunami).
- xi) Further proceeding towards village, a pit was dug at a spot (location 11° 23.073' N; 79° 49.112' E) near a grassy patch and about 20 cm of sandy tsunami deposit could be seen to overlie pieces of polyethylene packet and grass roots.
- xii) Some villagers informed that, on the tsunami day, around 07.00 AM, water was found in a pond where in normal conditions water never used to be there (~1.5 m deep).
- xiii) People believe that the tsunami came 3 times in this island and the timings of their coming are 08.30 AM, 09.00 AM and 09.15 AM.
- xiv) It was very difficult to confidently locate tsunami maximum inundation (zero water level) in this island as the village was inundated from both the sides. A villager showed us a small patch along the village road, which was not inundated. This man was not present in the village at the time of tsunami, but

he was told by others about that small patch where water did not reach. However, water marks on the nearby walls appear to suggest the level of tsunami water was negligible in that spot (locations, 11°23.016'N; 79°48.815'E and 11°23.032' N; 79°48.783' E).

3.3.16 PITCHAVARAM (Fig. 3-5, Site ID: 16, visited on 28/01/05)

- i) According to eyewitness Mr. S. Pakirisami (35 years), the tourist boat oarsman, who was at the Pitchavaram boat house jetty (location; 11°25.964'N; 79° 46.864'E), the tsunami appeared here as sudden rise of water with foamy front. Usually, everyday once in twelve hours water rises here due to tidal variation. However on tsunami day around 09:00 Hrs the rise of water level was very rapid (within about 10 minutes). As this rise appeared abnormal to the boatmen so they tried to secure their boats. They observed that within about an hour the raised water level gradually reduced to normal level. On the same day around 11:00 Hrs once again the backwater level rose rapidly and by about 12:00 Hrs, that water came down to normal level.
- ii) According to the other boat oarsman, on the tsunami day there was only two times abnormal rise of water level in the creek and the rise was rapid but fall was slow.
- iii) Accordingly to the boat oarsmen and local vendors of tender coconut and few villagers, the tsunami water in this area was at the jetty level, but through some low lying areas water reached near the toilet complex. There was some dried mud on the boat house garden ground, which according to the villagers were the tsunami derived sediment deposit.
- iv) Pitchavaram consists of backwater canals, small and big, with dense growth of mangrove plants. There are some four thousand canals, spread

over an area of 3000 acres, connecting the delta lands from Vellar river to Kollidam river. The backwater canals are covered with mangrove vegetation, which is very rare specimen in India). These mangrove forests have greatly reduced the tsunami impact. The backwater was crossed with rowing boat and sediment sample was collected from a tiny mud flat ($11^{\circ} 25.777'N$; $79^{\circ} 46.926'E$) from the western fringe of the mangrove forest area. It was observed that the stems of the mangrove plants are highly interwoven. This thick forest of interwoven mangrove plants may probably have decelerated the gush of tsunami water inflow shore wards and thus the areas shore wards of Pitchavaram mangrove forest were saved from the ravages of tsunami.

3.3.17 MUDASALODAI (Fig. 3-5, Site ID: 17, visited on 28/01/05)

- i) Mudasalodai is a fishing harbour at the bank of Vellar River. It was informed (by Dr. P. Chandramohan) that the sand spit in the mouth of Vellar River, has been severely eroded and almost the entire village located south of the spit have been flooded by tsunami waves. It was further informed that the sand bar at the mouth of Vellar River widened and deepened by tsunami. However once again the bar has started being formed.
- ii) The northern end of the sand spit was reached by crossing the Vellar River with mechanized dinghies. On the spit, indications of severe dune erosion were noticed. The boat drivers informed that these dunes were removed by tsunami.
- iii) Some fallen trees were found, but it appeared that they were representing local water flow direction towards low-lying areas rather than tsunami approach direction.

- iv) One eyewitness, boat owner-driver Mr. R. Kuppuswamy (37 years) said that at the time of tsunami arrival on 26.12.05, he was busy at Mudasalodai jetty for auctioning his fish catch. Suddenly he heard fisherwomen's shout that 'see big wave is coming'. On hearing that, he looked towards sea (along the river course approximately NE) and on seeing the approaching big wave, wanted to jump on his trawler and speed away. However he could not do so. According to him the approaching tsunami water appeared like a black muddy wall like water body with a foamy front.

- v) On Mudasalodai jetty level of tsunami high water level mark on the walls was taken with respect to backwater level. It was noticed that on the jetty at one place it is written +1.65m. On measurement it was found that the jetty height from the creek water level at the time measurement is also ~1.65m. So it can be considered that the level of tsunami high water level measured is with respect to mean sea level (MSL).

3.3.18 PORT NOVO (Fig. 3-5, Site ID: 18, visited on 29/01/05)

- i) According to eyewitness Mr. S. Vijayan (25 years), who works in the beach side NBK fishing company office at Port Novo, the first tsunami high water came around 08.40 AM (26/12/2004) in this site. He estimated this timing based on the fact that he started from his home at around 08.30 AM and just after he reached the NBK office, he heard people running. He looked seaward and saw many large waves coming. According to him the first one was small and the second was the biggest.. All these (a total of 6-7 waves) came within 15 minutes. He feels that, as water was at higher level due to the first wave, so the remaining waves went much shoreward. He feels that the Port Novo beach has neither widened nor narrowed. However he feels that the sand dunes in the spit (eastward of Port Novo) were flattened.

- ii) According to Mr. Vijayan the tsunami water of the first wave reached up to Port Novo lighthouse gate (Location 11°30.086' N; 79°46.254' E). Another location, where according Mr. Vijayan, tsunami water reached through Vellar River was found to be 11°29.294' N; 79°45.759' E. Location of another point in an open field in Parangipettai village (Chinnur South), where according to the villagers tsunami water has reached was found to be 11°30.276' N; 79°45.855' E

- iii) Clear tsunami high water level mark could be seen on Marine Biology Center building (Location; 11°29.472' N; 79°45.931' E) at Port Novo.

3.3.19 VELANGIRAYANPETTAI (Fig. 3-5, Site ID: 19, visited on 29/01/05)

- i) Villagers told that the water level was very high in this village and tsunami water submerged the village bus stand. However no houses on the sides of the beach approach road had clear water level mark. In one or two places dead sea-grass and weeds stuck in the thorny parts of the palm tree were found. Opposite to the bus stand a house could be found, where clear tsunami high water level marks could be seen in the inner walls of the room. The lady (Mrs. P. Dhanam, 40 years) owner of the house said that the first tsunami came around 09.00 AM (26/12/2004). When she saw the approaching waves at a distance of about 100 m towards beach, she got afraid and escaped through the backdoor of the house with her children.

- ii) It was interesting to note here that although the tsunami water level appears to be quite high in the village, not much sediment have been deposited as compared to other places visited so far. As informed, about 5 inches of sediment got deposited in the house of Mrs. Dhanam and those sediments were not sticky.

iii) According to one eyewitness villager, Mr. E Subhas (21 years) tsunami water has reached up to the Mariamman temple in the village. Mr. Subhas was on the beach when the tsunami came. He climbed up a Neem tree up to a height of about 7–8 feet and stayed there till the water level totally subsided. According to him the first tsunami came around 09.00 AM. This timing is based on the estimate that it came soon after the Parangipettai to Cuddalore bus left the village bus stand. This bus comes to the stand around 08.45 AM and waits for about 15 minutes. According to Mr. Subhas, the water did not come like a wall, but came as a sloping front.

3.3.20 REDDIYAR PETTAI (Fig. 3-5, Site ID: 20, visited on 02/02/05)

i) A survivor fisherman Mr. A. Mariappan (50 years) was on the beach and removing fishes from his net at the time of tsunami arrival. Suddenly he saw an approaching very high (about $\frac{3}{4}$ th coconut tree high) wave some distance away from the shore. That big wave broke and came rushing towards shore like an elevated water level. That first wave reached only up to his beach side huts. The second wave came as he and his family members were running shoreward after the first wave, but they could reach to safer place by that time. That first big wave appears to have arrived on the beach between 08:55 – 09:00 AM.

ii) As informed by several villagers, maximum tsunami water reach along the beach approach road was to a location about 75 m from the shoreline and its position was found to be Lat. 11°34.574' N, Long. 79° 45.372' E.

3.3.21 NANJALINGAM PETTAI (Fig. 3-5, Site ID: 21, visited on 02/02/05)

i) A surviving fisherman Mr. L. Thangaraj (65 years) was on the beach and removing fishes from his net at the time of tsunami arrival. Suddenly about 3-4 m offshore, he saw an approaching coconut tree high muddy water wall.

This water pushed Mr. Thangaraj landward and he managed to catch hold of a coconut tree and thus could save himself from being carried away further. When he hugged the coconut tree, the tsunami water was at his nose level (about 1.5 m) and soon afterwards the water started retreating. The approximate location, where Mr. Thangaraj was on the beach at the time of being hit by tsunami was Lat 11° 36.774' N, Lon 79° 45.579' E and the location of the coconut tree which he caught hold was Lat 11° 36.780' N, Lon 79° 45.555' E.

- ii) According to Mr. Thangaraj, no abnormal sound was associated with the approach of first tsunami and the water appears to have receded by about 50 m after the first inundation. After retreat of first inundation, Mr Thangaraj and his son-in-law collected their net, which was thrown in the coconut grove and started going towards the village and at that time ie. after about 10 – 15 minutes of the first wave, came the second big wave, which forced them to run shoreward leaving their net.
- iii) According to villagers the tsunami water, which inundated the village remained for longer time as huge sand dunes prevented fast draining.
- iv) As informed by several villagers maximum tsunami water reach along the beach approach road was about 372 m from the shoreline and the position of that location was found to be Lat 11°36.794' N, Lon 79° 45.373' E.

3.3.22 DEVANAMPATTINAM (Fig. 3-5, Site ID: 22, visited on 02/02/05)

- i) According to surviving fisherman Mr. U. Murthy (45 years), a resident of a beach side house, the first big tsunami wave hit this village shortly after 08:55 AM of 26 Dec'04. His estimate of this time is based on the fact that he telephoned someone around 08:55 AM and soon after he heard screaming

sound of people from the beach and on coming out of his house he saw a man being carried away by water over the beach approach road. On seeing this situation, Mr. Murthy ran inside his house and wading through chest high water he ran further landward through the backyard of his house along with one of his daughters. In the panic he forgot to pick his another daughter, who was deaf and dumb, therefore he came back as soon as the first wave receded from the village, and found his panic stricken 15 years old deaf and dumb second daughter safely sitting on the terrace of his single storied house.

- ii) As informed by several villagers, maximum tsunami water reach along the beach approach road was about 370 m from the shoreline and the position of that location was found to be Lat 11°44.741' N, Lon 79° 47.075' E.

3.3.23 PUDUKUPPAM (Fig. 3-4, Site ID: 23, visited on 01/02/05)

- i) A survivor fisherman Mr. S. Shivakumar (24 Yrs) was proceeding towards the beach at the time of tsunami arrival. Some other fishermen told him that the water is rising so it is necessary to pull the boats lying on the beach further shoreward. The day being a full moon day, the villagers thought that this rise of sea water is due to normal tidal rise on a full moon day but some what faster. However, when Mr. Shivakumar was trying to drag his boat further shoreward, then suddenly a big wave came and he was thrown about 100 meters shoreward. While being carried away, he felt like wave riding and his body did not touch the ground. The approximate location, where Mr. Shivakumar was standing on the beach at the time of being hit by tsunami was Lat 11° 51.939' N, Lon 79° 49.101' E and the location where he could stand inshore in chest level high water was Lat 11° 51.925' N, Lon 79° 49.059' E. Since he was thrown shoreward of his house, so immediately on recovery he ran towards his house to see what happened to his house and at that time he noticed that sea has receded exposing about 200 meters of

seafloor. After about 15 minutes, the water started rising swiftly and inundated the village. However according to Mr. Shivakumar, the inundation of the second tsunami wave was lesser than the first one. The tsunami water front was muddy and foamy. The first tsunami big wave appears to have hit this village around 08:45 AM of 26 Dec'04 and the second wave came around 09:00 AM.

- ii) A tsunami debris line, most likely defining the tsunami maximum inundation limit could be easily noticed at the end of the transect and the following positions were obtained along the out line of that debris line;

- a) Lat 11° 52.058' N, Lon 79° 49.088' E
- b) Lat 11° 52.060' N, Lon 79° 49.087' E
- c) Lat 11° 52.066' N, Lon 79° 49.093' E
- d) Lat 11° 52.069' N, Lon 79° 49.100' E
- e) Lat 11° 52.078' N, Lon 79° 49.100' E

3.3.24 PONDICHERRY PORT JETTY (Fig. 3-4, Site ID: 24, visited on 29/01/05)

- i) A tsunami eyewitness Mr. Pulendhiran (Port Department, Pondicherry Port), who was at the port jetty gate at the time of arrival of tsunami at this site. According to him the sea was normal as usual before arrival of tsunami. A number of fishermen were fishing from a boat and jetty pier in the southern side of the jetty. Suddenly the fishermen observed that the water level was rising very fast. So they got afraid and jumped from their boats to the jetty. This higher water level hit the eastern side of the port wall around 08.30 AM and stayed for about half an hour. Then that higher water level suddenly receded by about 155 m exposing about 150 m of the seafloor east of the stone breakwater. The second time tsunami high water came around 09.20 AM and stayed for about 15 minutes and then again receded. After that slowly the sea level became normal, but the sea condition became slightly rough.

- ii) Mr. Pulendhiran supported his observation of seawater receding (after the first flooding) by stating that he was able to see the western half of the sunken barge lying in east –west orientation alongside the southern side of the jetty. The eastern end of the pump house (11°55.358' N, 79°50.039' E) over the jetty up to where, according to Mr. Pulendhiran, sea receded suggests a sea withdrawal of about 150 m. The water depth at this place was measured to be about 4.7 m (depth measurement time 29/1/2005; 17:00 Hrs)
- iii) Number of photographs taken by the port officials undoubtedly recorded the sea water withdrawal in this area. The fact that the receded sea stayed in that condition for quite some time is evident from the photograph of people loitering in the receded seafloor and running landward on seeing the approaching tsunami.

3.3.25 PERIAKALAPET (Fig. 3-4, Site ID: 25, visited on 01/02/05)

- i) According to tsunami surviving fisherman Mr. B. Ganeshan (34 Yrs), there was no abnormal sound from the sea before the arrival of tsunami.
- ii) According to tsunami survivor Mr. R. Manivannan, the first tsunami wave hit the village around 08:45 AM of 26 Dec '04 and this first wave reached farthest along the beach approach road. The rushing tsunami water front was looking like rolling muddy water.
- iii) According Mr. N. Selvanathan and Mr. I. Sellappam, the two tsunami surviving fishermen from the village, who were standing on the beach at the time of arrival of tsunami, the first tsunami wave came inshore by about 5 meters and then receded. The big tsunami wave came riding on this receding water. When the big wave hit the beach, all of a sudden, the fishing boats lying on the beach were floated to their head level. According to them, the time of

arrival of first tsunami wave is around 08:50 AM of 26 Dec '04. These two persons were carried away inshore by first tsunami big wave. On recovery from shock after being drooped in the village ground, these two persons came running to the beach to search for their nets. At that time, they noticed that the sea receded by about 500 meters. Since this receding of water which stayed for about 10 – 15 minutes appeared to them as abnormal phenomena and made them afraid of some unforeseen dangerous situation. At that time, they noticed a very big wave approaching the beach from a distance of about 1 Km offshore, and on seeing that big wave, they ran for the high ground and saved themselves.

- iv) The location of maximum tsunami water reach (as informed by several villagers) along the beach approach road was found to be 12° 01.713' N, Lon 79°51.936' E.
 - v) The coconut trees apparently have fallen after being hit by tsunami suggest a tsunami approach direction at this site from NE to SW.
 - vi) No black sand was noticed in the surficial beach deposits of this site.

3.3.26 NOCHIKUPPAM (Fig. 3-4, Site ID: 26, visited on 03/02/05)

- i) Two surviving fishermen Mr. A. Rajan (26 Yrs) and Mr. S. Ramachandran (46 Yrs) were on the Nochikuppam village beach and collecting fishes from the net at the time of arrival of tsunami. Suddenly they noticed that the water is rising rapidly and their boats stacked on the beach becoming afloat and started hitting each other. At that time one person from the village shouted that a dangerously high wave is approaching from the sea and on hearing that Mr. Rajan ran towards village.

- ii) According to another villager, after the initial rapid rise (which caused hitting of boats) came a big wave, which carried Mr. Ramachandran inside the village. According to Mr. Ramachandran, while being carried away by tsunami, his motion was a confused combination of running, swimming and floating till he managed to reach a slightly higher ground and stand. Mr. Ramachandran further informed and other villagers concurred with him that, the second big wave came before the high water of the first tsunami wave receded to normal sea level. The villagers could not say whether there was any third or subsequent tsunami wave as all of them ran away from the coast soon after the second wave hit the village. However one thing they all confirmed that, there was no receding of sea beyond the normal shoreline at least before or after the first tsunami wave.

- iii) According to villagers the first tsunami wave appears to have hit this village coast around 08:30 AM and the waterline appears to have advanced shoreward as compared to pre tsunami days.

- iv) It was observed that several boundary walls of the masonry houses of a fishermen's colony in this village were damaged by tsunami. The force of the tsunami wave appear to have been quite high here as some of the masonry wall portions measuring about 1.2 m X 1.4 m X 0.12 m were moved by about 8 – 10 m from their original position. It was interesting to notice that despite this strong tsunami wave force, nothing happened to any trees in a nearby coconut grove.

3.3.27 EKKIYARKUPPAM (Fig. 3-4, Site ID: 27, visited on 03/02/05)

- i) A tsunami surviving fisherman Mr. S. Shiva (22 Yrs) was standing on the Ekkiyarkuppam beach at the time of arrival of tsunami. Suddenly he noticed that the water is rising rapidly and the boats stacked on the beach becoming afloat and started hitting each other. Seeing this situation Mr. Shiva thought

some cyclone is approaching. This first rise of water continued till it reached far inside the village., The fishermen on the beach tried to save their boats till the water level was knee deep. But when the water rose to their forehead level, they thought something unusual is happening, so they ran towards village.

- iii) According to Mr. Shiva, the first tsunami appears to have arrived in this beach around 08:30 AM and there was no abnormal sound before the arrival of tsunami. As soon as the first wave receded, Mr. Shiva and other fishermen came to the beach to see the fate of their boats. At that time they saw that the sea has receded by about 500 meters and on the exposed seafloor many small (~ 10 – 15 cm long) fishes were jumping. This receded sea stayed for about 10 – 15 minutes after which the sea started rising again. However the second water rise came like a very big wave but that rise did not stay long and when it receded the sea also receded. There was a third tsunami wave in this area around 09:00 AM. The colour of the tsunami water was that of a mixed mud and sand.
- iv) As informed by several other villagers, maximum tsunami water reach in the village was to a location about 150 m from the shoreline and position of that location was found to be Lat 12° 10.937' N, Lon 79° 57.591' E.
- v) According to villagers the waterline advanced shoreward after the tsunami.
- vi) A fishing net was found lying on the shrubs adjacent to the beach. The trailing of the net appears to suggest the direction of tsunami wave at this place was from ESE (280° bearing).

3.3.28 KOTTAIKADUKUPPAM (Fig. 3-4, Site ID: 28, visited on 03/02/05)

- i) This is a village behind back waters which has a small opening to the sea. A small island towards east across the backwaters protects the village from the vagaries of the open sea. A location on the bank of backwaters was found to be Lat 12° 14.700' N, Lon 79° 58.990' E and the location of the tsunami inundation limit on the adjacent paddy field was found to be Lat 12° 14.775' N, Lon 79° 58.858' E. Though this inundation appears to be quite extensive, but the heights of tsunami water level marks did not suggest appreciably high level of water. Perhaps the island facing the village saved it from the high tsunami water and the water intruded longer distance onshore due to low lying paddy fields having no bunds / roads to obstruct the tsunami water flow.
- ii) It was informed that the prior to tsunami lot of oysters used to have been harvested from the bed of these backwaters. However these oysters were no more available after the tsunami.

3.3.29 SADURANGPATTANAM (Fig. 3-3, Site ID: 30, visited on 04/02/05)

- i) The village is situated between Kalpakkam atomic power plant in the north and atomic power plant staff colony in the south. The beach is relatively steep and long open type beach.
- ii) The tsunami survivor Mr. M. Dhanapal (36 years) stays in a house very close to the beach. On the tsunami day he had come to the beach in the morning to work for the fishermen around 9.00 AM when some were mending their nets and some were taking the fish from the net. Mr. Dhanapal suddenly observed very rapid rise in the sea level. This rise was anomalous compared to the spring/neap tide. Further the rapid rise of water was causing the dangling and the hitting of the boats pulled ashore. This rapid rise and advancement of water towards the village continued. So he ran towards his

house and while doing so he was hit by the rising water and he reached his home partly running and partly floating/swimming. When he reached his house, the water rose to his neck level (1.5 m). This water flooded the village. After this flooding, the water started receding. According to him the speed of receding water was at least 3 times the speed of incoming water. Further he also noticed (and other villagers present during our interview reiterated) that the flooding water level was like level surface. The villagers think that the damage to the village was relatively less due to this level surface of the flooding water. Further according to Mr. Dhanapal the first water rise receded beyond the normal shoreline by about 50 m (which was inferred by him from the exposed seafloor). After this recession, the water behaved like normal breaker for about 5-6 times, during which water didn't cross the shoreline.

- iii) After this came the second big wave and the village again got inundated. Seeing the incoming second big wave, Mr. Dhanapal ran towards the police station at the end of the village and he doesn't know anything further.
- iv) The villagers told that there was no anomalous sound during arrival of tsunami. The deposited mud in their house was stinking and they don't see any change in the shoreline position after the tsunami, but they feel slight rise in the beach level.

3.3.30 MAHABALIPURAM (Fig. 3-3, Site ID: 31, visited on 04/02/05)

- i) At Mahabalipuram beach well recognizable tsunami water mark could be seen in the shops located on the southern side of this beach approach road. However the maximum inundation line (zero water levels) couldn't be well defined along this road as the road level suddenly was raised. However maximum inundation (location 12°36.945' N; 80°11.775' E) line was recognizable on the adjacent dune from tsunami debris line (of grass, weeds etc.).

- ii) According to shop owners on the beach approach road, tsunami approach direction was approximately perpendicular to the shoreline. Further from a photograph, of tsunami water flooding the temple complex park, it appears that the tsunami flooding here was nearly in the same direction as the inundation transect. In a nearby fishing village in the north (Pattipulam 12°41.238' N; 80°13.287' E) fallen debris of a wall broken by the tsunami had bearing of 270° and the orientation of a fallen coconut tree was found to have a bearing of 260°. It appears, the waves hitting Mahablipuram / Pattipulam approached nearly from east.

3.3.31 KOVALAMKUPPAM (Fig. 3-3, Site ID: 32 , visited on 05/02/05)

- i) A surviving fisherman Mr. M. Rajaratnam (20 Yrs) was on the Kovalamkuppam village beach and collecting fishes from the net at the time of arrival of tsunami. Suddenly, he noticed that the sea is rising very rapidly. This rising sea water reached a little higher level than maximum reach of normal highest high tide and immediately afterwards this water started receding very fast. The sea receded so far seawards of normal waterline and exposed the seafloor, that Mr. Rajaratnam could see the base of the rock outcrops, whose tips were only visible in normal lowest low tide days. He could even see many fishes jumping on the exposed seafloor. Shortly afterwards the sea started rising again slowly and that slow rise was followed by a big wave, which advanced very fast and inundated the village. All the time the advancing high water surface was looking like a silently overflowing boiling milk surface.
- ii) According to villagers the first tsunami wave appears to have hit this village coast around 08:30 AM, the second one around 08:35 AM and a third one around 08:50 AM. The clock was showing 09:00 AM, when all the tsunami waves subsided and villagers came back to the village.

- iii) A fisherman Mr. R. Muthukrishnan (27 yrs.) was busy catching fish on a boat in the sea at about 25 fathoms water depth zone, at the time of the tsunami. He noticed that the net or lines was not touching the bottom on that day as they normally do in that area. Otherwise he did not observe anything abnormal in the sea during tsunami time.

3.3.32 KARIKATKUPPAM (Fig. 3-3, Site ID: 33 , visited on 05/02/05)

- i) A surviving fisherman Mr. C. Rangaswamy (55 Yrs) was sitting on the Karikatkuppam village beach at the time of arrival of tsunami. He did not notice or hear any thing abnormal until he observed that his catamaran was being pushed shoreward by the sea. After that suddenly he was carried away shoreward to the village by tsunami and was rescued by his children.
- ii) In this beach, thin layers of black sand patches were observed at places.

3.3.33 URUR ALCOTTKUPPAM (Fig. 3-2, Site ID: 35 , visited on 05/02/05)

- i) A village lady informed that first she noticed that the fishing boats which were kept on the beach were being pushed by sea westwards towards the village houses. This rising sea started receding before it reached the village and the receding sea took the waterline eastward of normal shoreline by about 50 meters. Following this receding water came a big wave, which inundated the village. After that several big waves came and such situation continued till about 14:30 Hrs.

3.3.34 NARARTHOTTAM (Fig. 3-2, Site ID: 36 , visited on 05/02/05)

- i) On the tsunami day morning a fisherman, Mr. R. Sundaram (35 yrs.), was fishing with lines on a fiber glass boat in areas of water depth of about 15 fathoms. Around 09:00 AM – 09:30 AM he observed unusual ‘to and fro’ and

some sort of whirlpool like motion in the sea. However his fishing lines, which were kept with floats, did not get entangled. In this coast, during lowest low tide, the sea recedes by about 10 m from the normal waterline. However, on the tsunami day when Mr. Sundaram was returning to shore around 01:30 PM, he observed that the waterline has receded by about 50 meters and the boats were hitting the stones / rocks of the seafloor.

- ii) A fishing boat crew, who was on the fisheries jetty was suddenly alerted by his boat man that something like a cyclone is approaching. Usually when cyclone comes, the fishermen take the boat towards inner harbour for safety. With the same intention, he tried to release the rope by which the boat was tied to a pier on the jetty. But he could not as it was taut perhaps due to the fact that the boat was being pushed by water with great force. Soon he noticed a big wave approaching, and ran for safety, however at that time the water level in jetty reached to his knee level.

3.3.35 BEEMARUPALAYAMKUPPAM (Fig. 3-2, Site ID: 37 , visited on 06/02/05)

This village is on the bank of Pulikat lake, which is a very large brackish water lake (~60 km x 17 km), connected with the open sea by a narrow opening situated about 29 km southeastward of the village. On tsunami day the villagers noticed entry of sea water like a flowing river some time during 09:45 AM – 10:00 AM. Due to this fast entry of seawater the water level of the lake rose to some height. However, according to the villagers the water rose to a much higher level during 1984 cyclone.

3.3.36 KRISHNAPATNAM (Fig. 3-1, Site ID: 38 , visited on 06/02/05)

The situation at the time tsunami in the KRISHNAPATNAM fisheries port inner harbour was observed by the port officials and the situation at the harbour mouth

and open coast was observed by the crews of a dredger, which was dredging at the harbour mouth. According to them:

- a) The first wave arrived around 09:15 AM. In the open coast, suddenly the sea rose like a four (4) meters high wall and inside harbour by about 2 meters. During this rising of sea, the barges and boats in the harbour area started drifting erratically.
- b) This raised sea stayed for about 30 – 45 minutes, after which it started receding. The recession in the open coast area outside the harbour was fast within about 5 minutes. Whereas inside the harbour the recession was much slower.
- c) The water receded to such an extent that sandbar in the harbour mouth got exposed over large areas and the dredger got grounded. Subsequently around 11:00 AM came the second large wall like wave, which was the biggest and the dredger capsized on being hit by that wave. Even after that, big waves continued to arrive, but they were not as high as the first two. This erratic behaviour of the sea appears to have continued for about 3 days.

3.4 Tsunami transported sediments

The tsunami appears to have transported large amount of, mainly sandy sediments, onshore. At many places these sandy materials are black consisting of heavy minerals. However, at this time it is difficult to infer whether all those black sands were tsunami transported. Nevertheless at several locations black sand layers surely could be found in the confirmable tsunami transported sedimentary unit. Following are some preliminary inferences from the sediment samples collected during this survey. Summary information about these samples are presented in Table 5.

- i) In the areas south of Samanthanpettai the tsunami transported sediments were mainly of fine grained compared to north of Samanthanpettai.
- ii) Black sands on surface sediments were found in several beaches. The thickness of the black sand layers varied between 2 – 5 cm. The beaches with such deposits are: (i) southern sector between Nagore and Karaikal, (ii) middle sector between Devanampattinam and Periakalapet and (iii) the northern sector between Sadurangapattanam and Karikattukuppam.
- iii) At many places, the pit sections of confirmable tsunami deposits depict presence of distinct bands of black and lighter colour sands.
- iv) The thickness of black sand layer in the tsunami transported sediment was found to be maximum of about ~ 12 cm at Reddiarpetai.
- v) At places, where the tsunami water appears to have stagnated or backrush was slow, there the top sediments deposits were found to be of silty clay.
- vi) The depositional environment thus appears to have fluctuated between episodes of high energy and low energy regime during the tsunami.

3.5 Surface sea water quality

The results of analysis are presented in Table 4. In the studied area the concentration of chemical parameters in the surface sea water are as follows:

- i) Dissolved oxygen concentration varies from 1.72 ml/l to 5.89 ml/l.
- ii) Phosphate-phosphorus concentration varies from 0.17 μM to 1.62 μM
- iii) Silicate-silicon concentration varies from 2.72 μM to 236.36 μM .

3.6 Littoral environmental observation (LEO)

It is observed that the breaking wave heights were seen higher (1 – 1.75m) in northern region compared to the southern region (<1m except at Tarangambadi) and so were the wave periods. The Longshore current was predominantly northerly over the region and at remaining locations it was southerly. The northerly longshore currents were seen to be greater in magnitude (11-28 m/min) compared to the southerly currents (4-12 m /min).

The median grain-size (D_{50}) values of the sediments north of Poompohar were observed to be higher compared to the sediments south of Poompohar. This could be due to the wave climate, which is higher on the north compared to the south.

The LEO values are presented in NIO Technical report no. NIO/TR-03/2005

Section – 4

SALIENT INFERENCES

During the course of this post-tsunami reconnaissance survey several measurements and observations were carried out along the tsunami affected coastal tract of Tamilnadu, Pondicherry and Andhra Pradesh. Following are the salient inferences about some of the aspects of nature, behaviour and impact of the tsunami in the study area.

- A. The inundation and run-up measurement suggested that:
- i) Maximum inundation limit (i.e. maximum lateral landward penetration of tsunami) was about 862 m at Nagore and the minimum inundation was about 31 m at Kottaikadu Kuppam.
 - ii) Maximum run-up of about 6.54 m (above chart datum) was observed at Periyakalpet (Pondicherry) and the minimum run-up of was about 2.20 m at Krishnapatnam.
 - iii) The tsunami water traveled along the river course several kilometers upstream.
- B. The orientation of imprints of tsunami water flow appears to suggest that the bearing of tsunami on the coast was about 240° in the areas south of Samanthanpettai and in the areas northwards from here the tsunami bearing, in general, veered towards 270° or more.
- C. There was a variation in the magnitude of tsunami along various locations and in many places the second wave appears to have been the biggest.

- D. The observed tsunami affected structures suggest that;
- i) In majority of the cases the structural failures appear to have occurred due to inferior quality of construction.
 - ii) Close proximity to the sea, very shallow foundation depth and drainage pattern around the structures are the other common reasons for the observed structural failures.
 - iii) Observed failure in the structures were due to scour, unequal settlement caused by scour around the structure, tensile, compressive, torsional and combination all these forces
 - iv) The momentum of tsunami waves was sufficient enough to cause even steel power transmission tower to fail (combined tension and torsion failure).
- E. Natural barriers such as sand dunes and coastal vegetation (casuarinas, palm, coconut, sand dune grass and mangroves) have played a major role in minimizing damage due to tsunami.
- F. The tsunami transported large amount of sediments onshore. At many places these sediments contain layers of black sand. The depositional environment appears to have fluctuated between episodes of high energy and low energy regime during the tsunami. At places there were considerable erosion. The erosion in the villages largely appears to be associated with the backrush of tsunami. In the open sea coasts presence of weak points, such as narrow gullies, edges etc. appear to have facilitated initiation and accentuation of erosion of dunes etc.

G. Based on eye witnesses report and other available information it appears that:

- i) There were up to three main pulses of tsunami. Perhaps many smaller pulses of the tsunami continued to affect some areas for several hours after the main event.
- ii) The first tsunami arrived around 08:40 Hrs near a central sector around Samanthanpettai – Tarangambadi tract. The arrivals were slightly afterwards in the areas north and south of this tract.
- iii) At Pudukuppam and areas in the north, the tsunami tended to be seen as a very swift rising of sea level whereas in the areas south of this place the arrival of tsunami was like a sudden huge muddy coloured wave / wall of water.
- iv) The withdrawal of sea associated with tsunami appears to have been distinctly noticeable in the areas northwards from Pondicherry.
- v) Anomalous sound (like passing of helicopter at distance) preceded arrival of tsunami in the areas south of Thirumullaivassal, whereas in the areas north of this place no anomalous sound was heard.

H. The dissolved oxygen values in the surface sea water indicate that the near shore waters along the coast is well oxygenated (1.72 – 5.89 ml/l).

REFERENCES CITED

- Annonymus (2001). Tsunami warning systems and procedures: guidance for local officials, Oregon Department of Geology and Mineral Industries, Special Paper 35, Oregon, USA
- Grasshoff, K., Ehrhardt, M. and Kremling, K. (1983) Methods of seawater analysis, Verlag Chemie GmbH, Weinheim, Germany, p 419.
- IOC,(1998). Post-tsunami survey field guide (first edition), Intergovernmental Oceanographic Commission (UNESCO) Manuals & Guides, No. 37, 32 p.
- Kaitoku, T. (2002). Tsunami surveys and measurements, in the web page of the International Coordination Group for the tsunami warning system in the Pacific, (URL: <http://ioc.unesco.org/itsu/>)
- NIO, (2005), Inundation limit, run-up heights, cross-section profiles and littoral environment along Tamil Nadu Coast after 26th December 2004 tsunami. National Institute of Oceanography, Technical report no. NIO/TR-03/2005.
- Ruffman, A., (1996). Tsunami run-up mapping as an emergency preparedness planning tool: The 1929 tsunami in St. Lawrence, Newfoundland. Geomarine Associates Ltd., Contract Report for Emergency Preparedness Canada (EPC), Office of the Senior Scientific Advisor, Ottawa, Ontario, Vol. 1 — Report, 107 p.; Vol. 2 — Appendices and Enclosures, 281 pp.
- Wessel, P. and Smith, W. H. F., (1995). New version of Generic Mapping Tools released, EOS, Trans. American Geophysical union, V76, pp. 329.

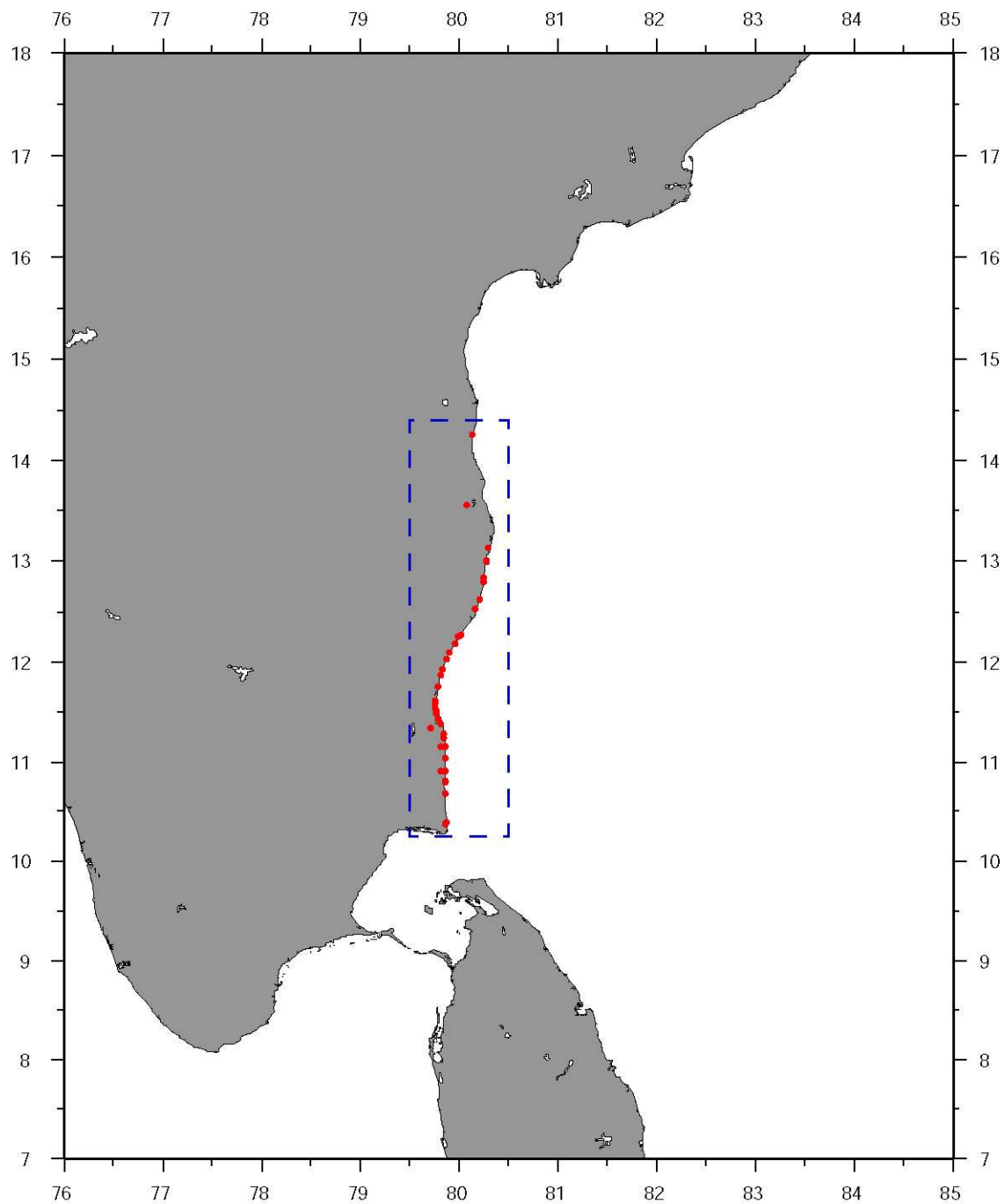


Fig. 1. Map showing study area along the Indian coast. The coastal tract within the boxed area (dashed boundary) was covered under the present study and the red dots are the sites visited.

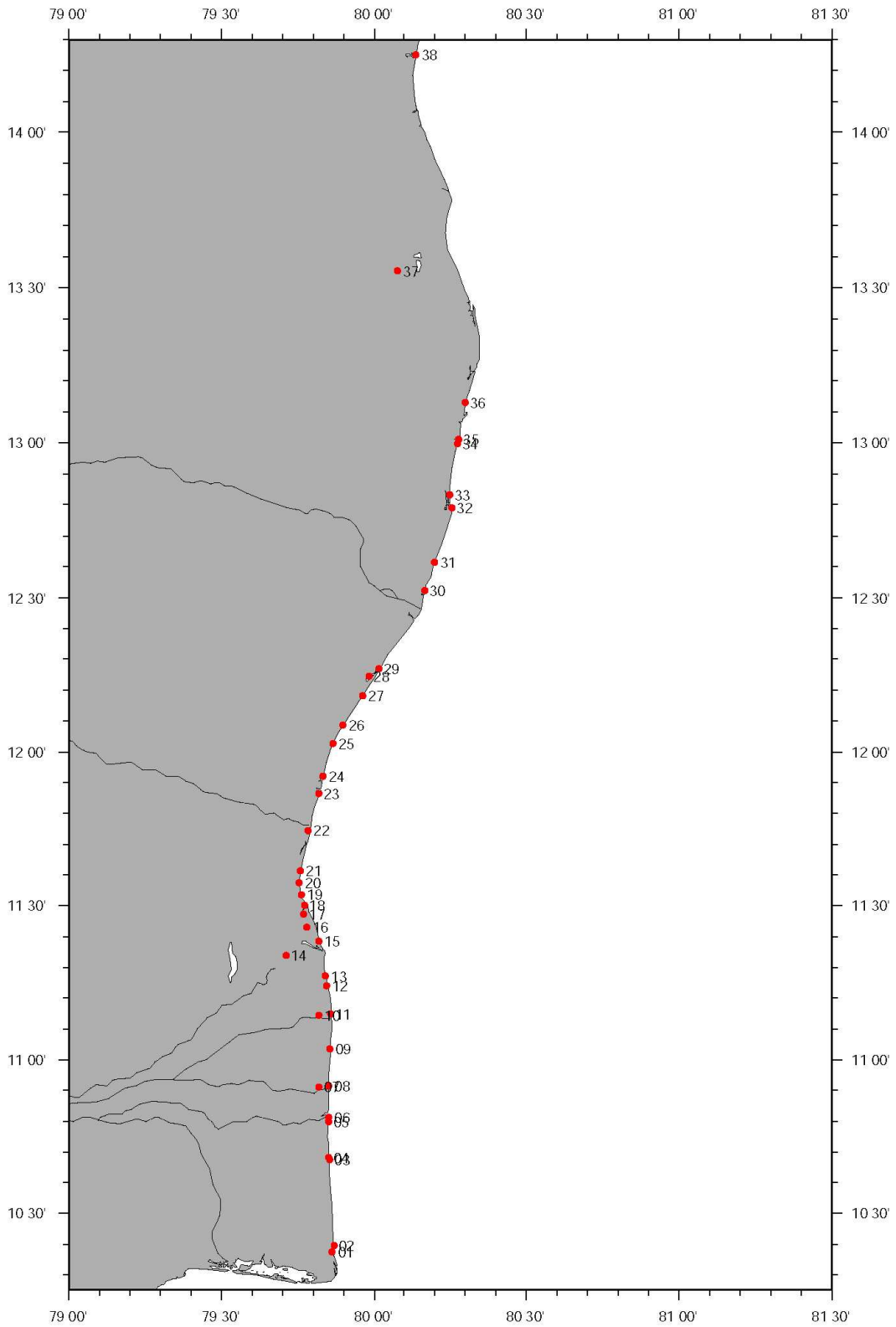


Fig. 2 Map showing location of sites visited (red dots). Number by the side of site location is the site ID. Name of the site and other details are as given in Table 1.

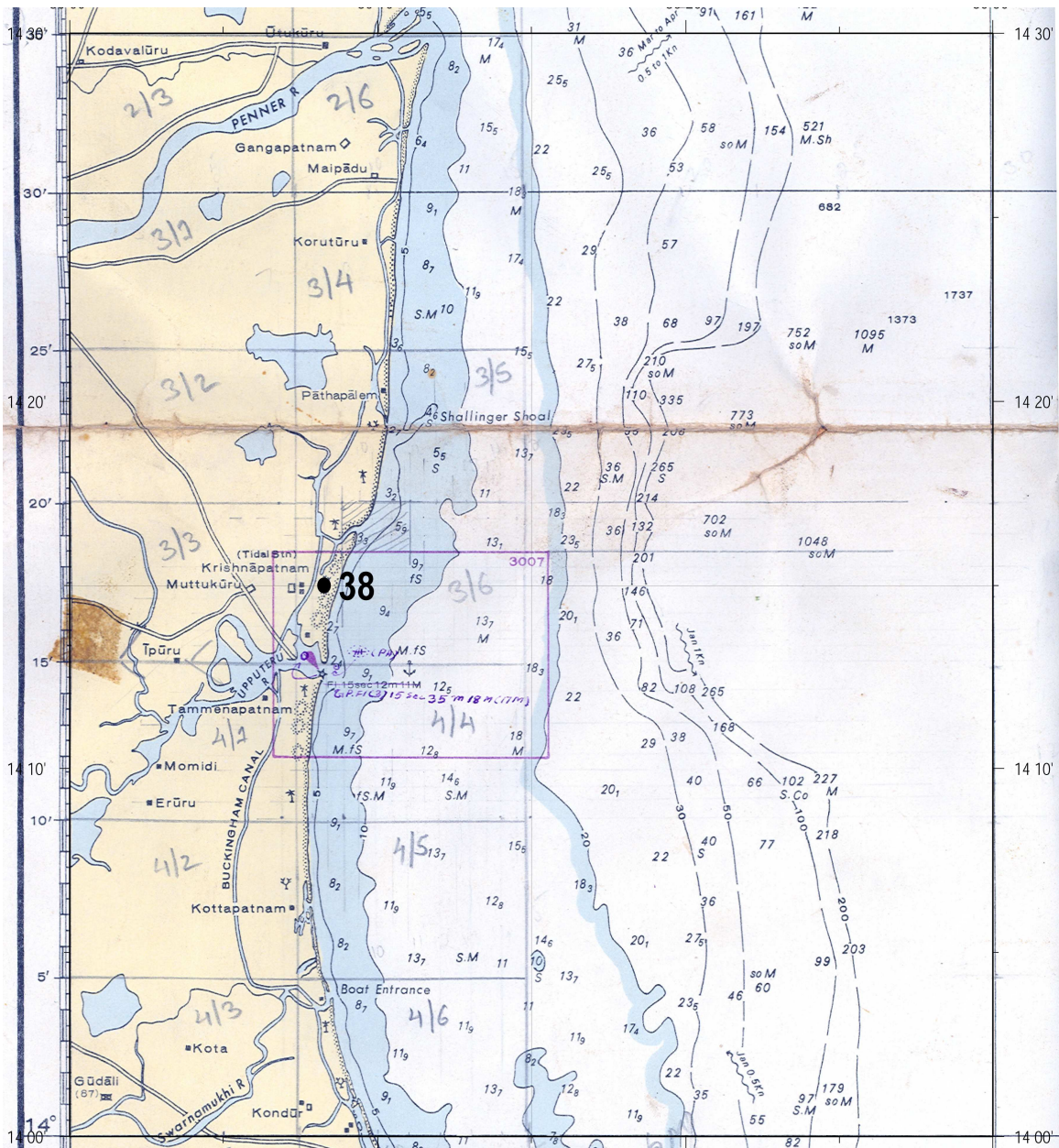


Figure 3 – 1. Locations of survey site 38 shown with solid black dots in the background image of hydrographic chart. Number by the side of site location is the site ID. Name of the site and other details are as given in Table 1.

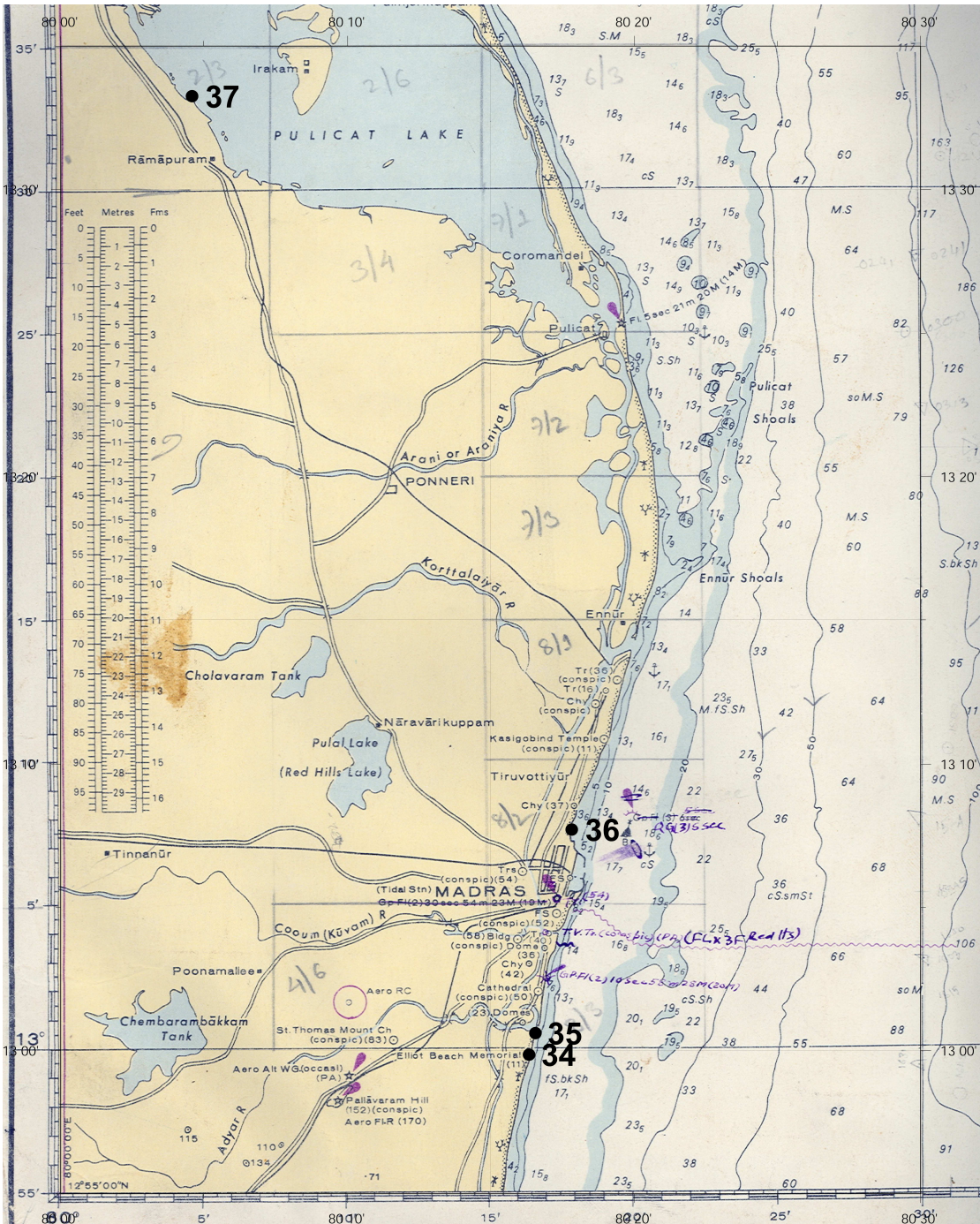


Figure 3 – 2. Locations of survey sites 34 – 37 shown with solid black dots in the background image of hydrographic chart. Number by the side of site location is the site ID. Name of the sites and other details are as given in Table 1.

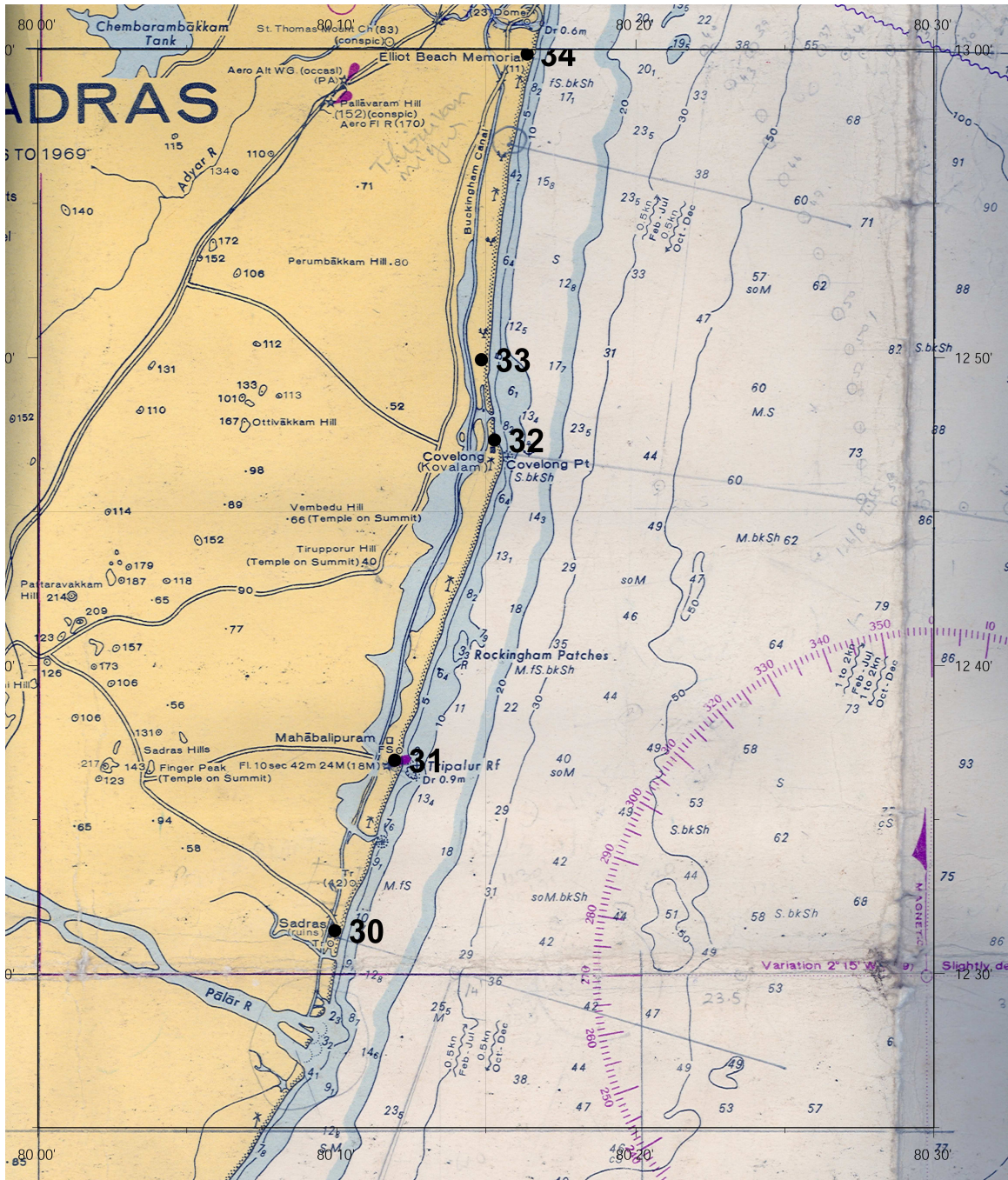


Figure 3 – 3. Locations of survey sites 30 – 34 shown with solid black dots in the background image of hydrographic chart. Numbers by the side of site location are the site ID. Name of the sites and other details are as given in Table 1.

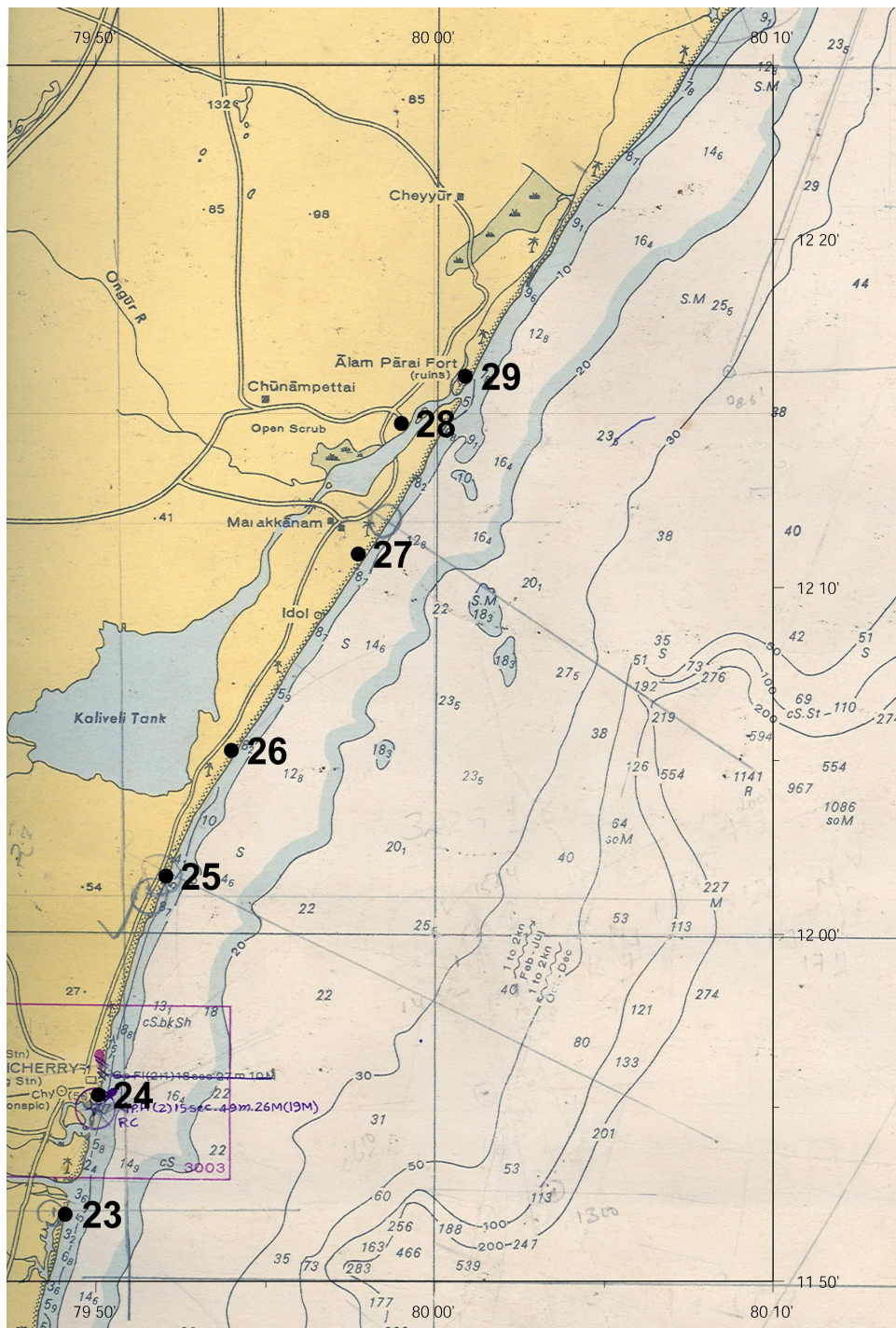


Figure 3 – 4. Locations of survey sites 23 – 29 shown with solid black dots in the background image of hydrographic chart. Numbers by the side of site location are the site ID. Name of the sites and other details are as given in Table 1.

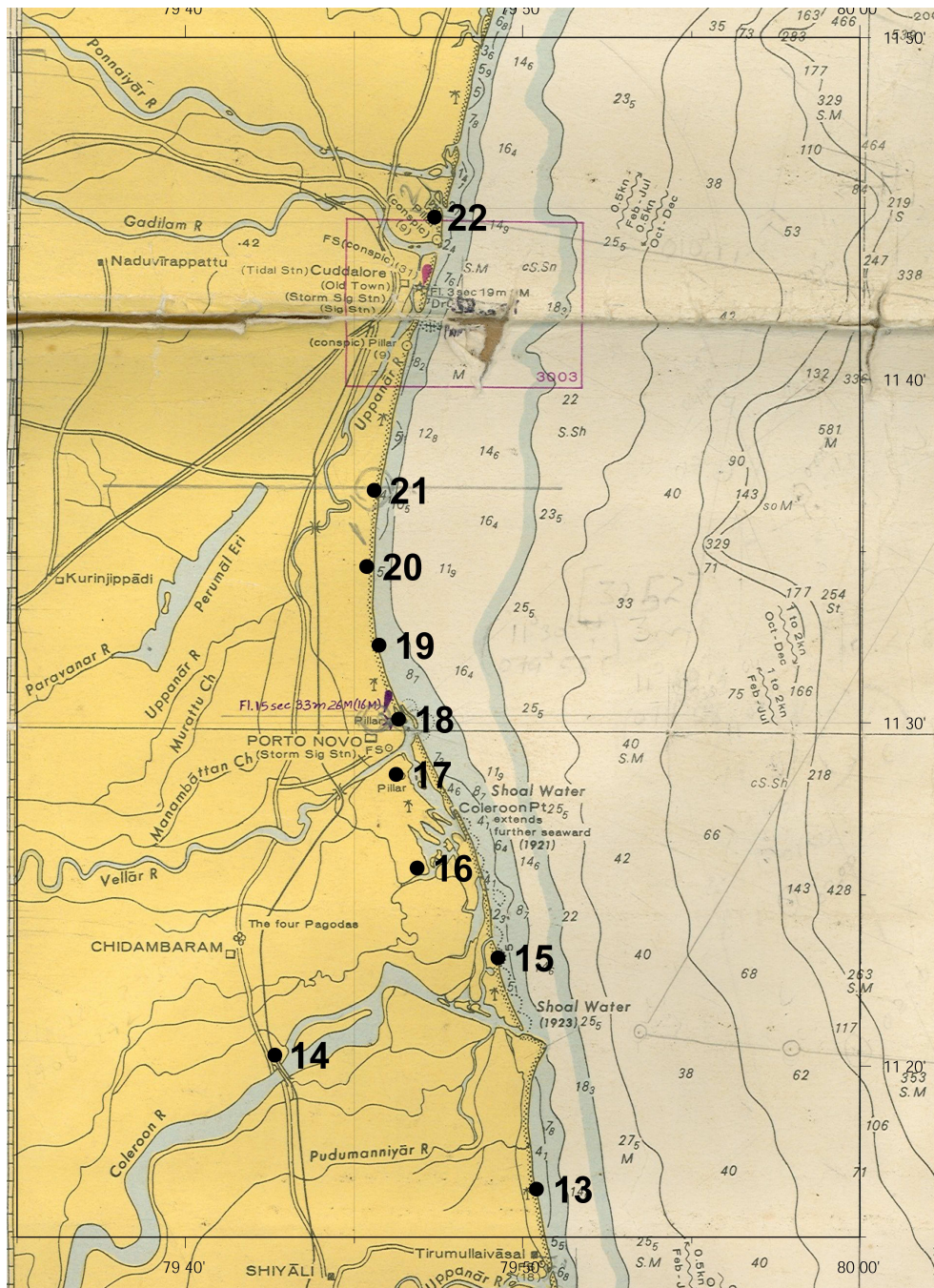


Figure 3 – 5. Locations of survey sites 13 – 22 shown with solid black dots in the background image of hydrographic chart. Numbers by the side of site location are the site ID. Name of the sites and other details are as given in Table 1.

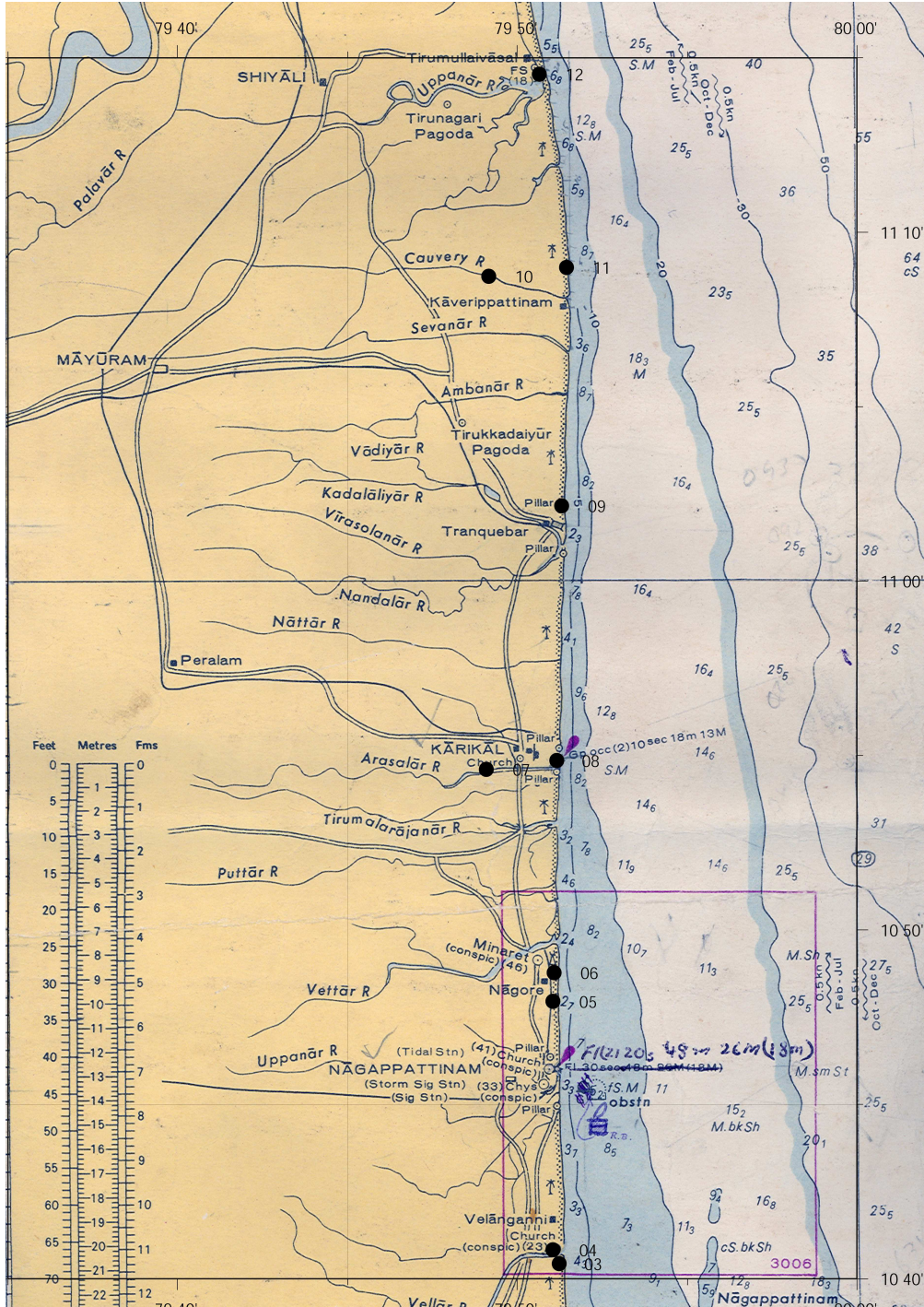


Figure 3 – 6. Locations of survey sites 03 – 12 shown with solid black dots in the background image of hydrographic chart. Numbers by the side of site location are the site ID. Name of the sites and other details are as given in Table 1.

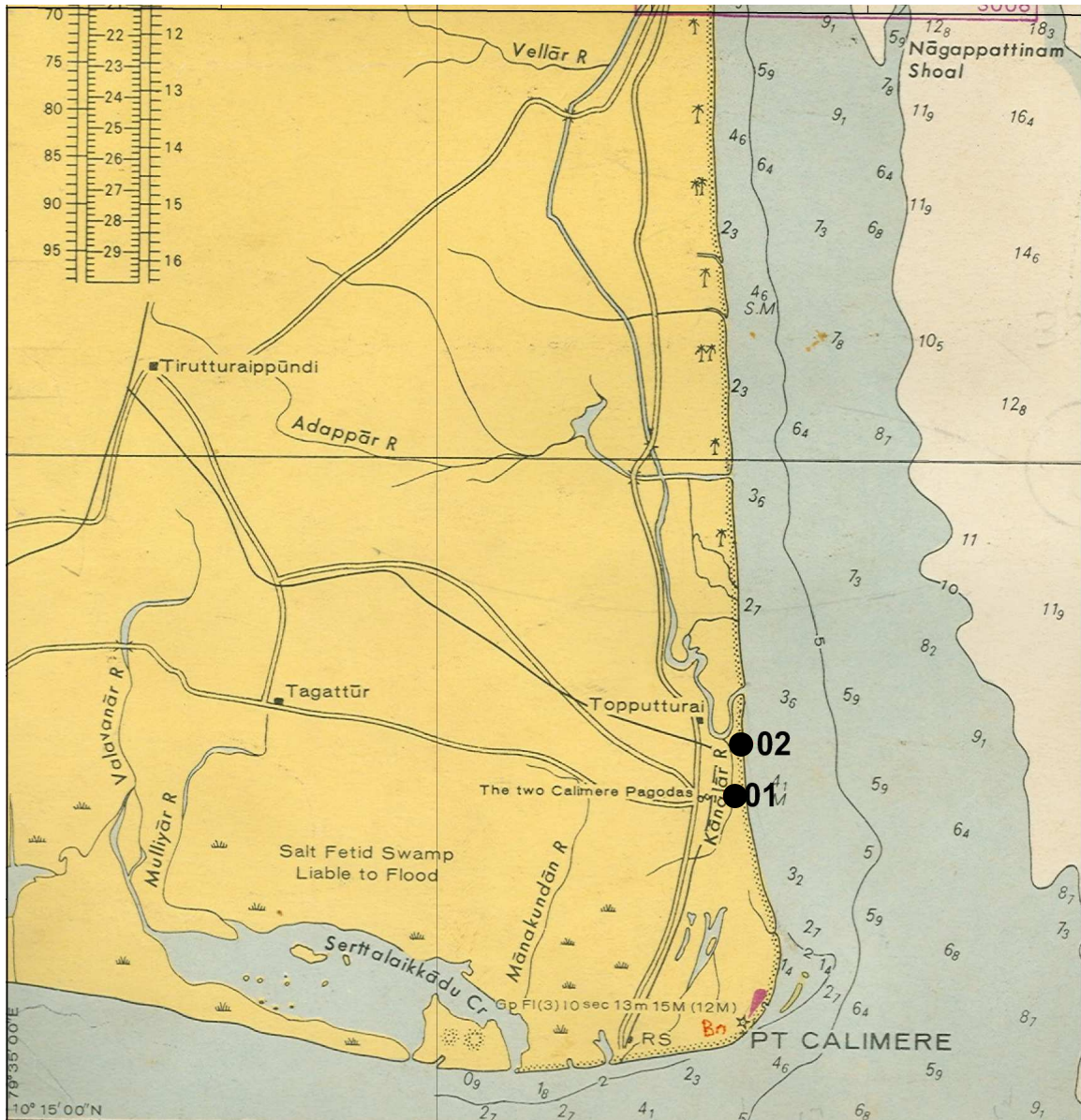


Figure 3 – 7. Locations of survey sites 01& 02 shown with solid black dots in the background image of hydrographic chart. Numbers by the side of site location are the site ID. Name of the sites and other details are as given in Table 1

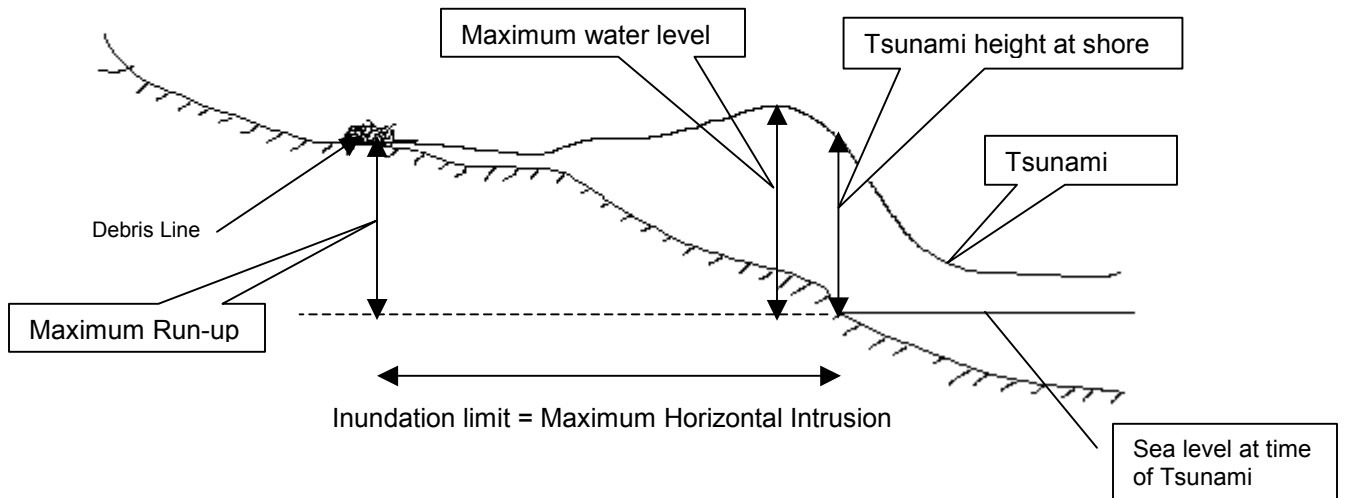


Fig. 4. Schematic drawing shows tsunami interaction at the coast describing the tsunami inundation/run-up related parameters.

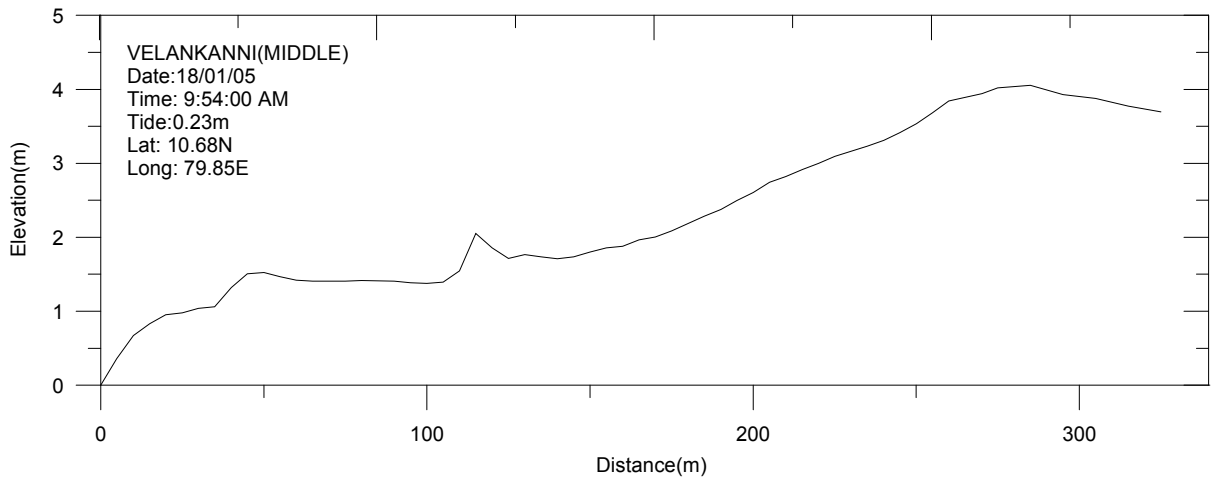
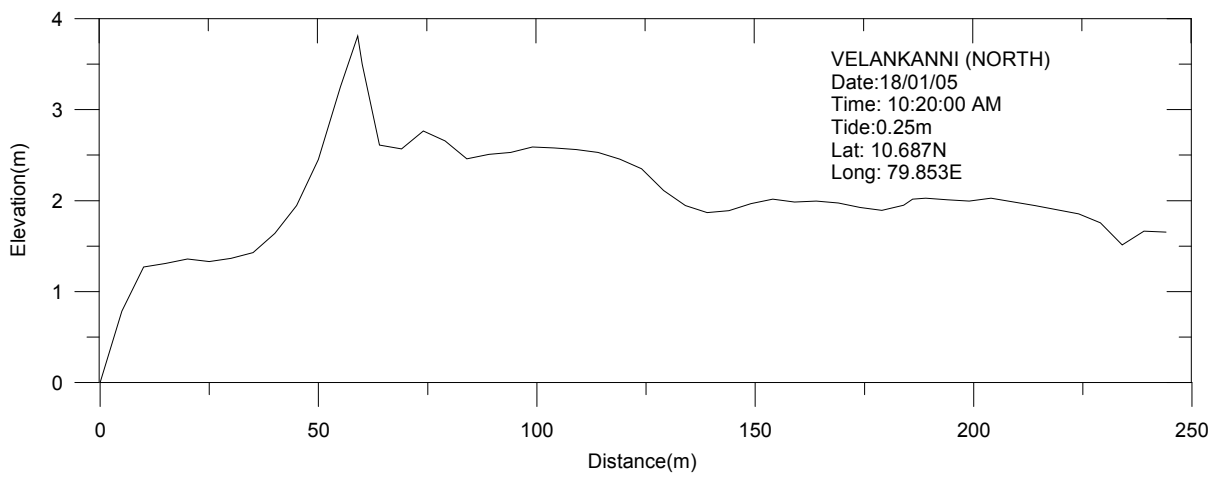
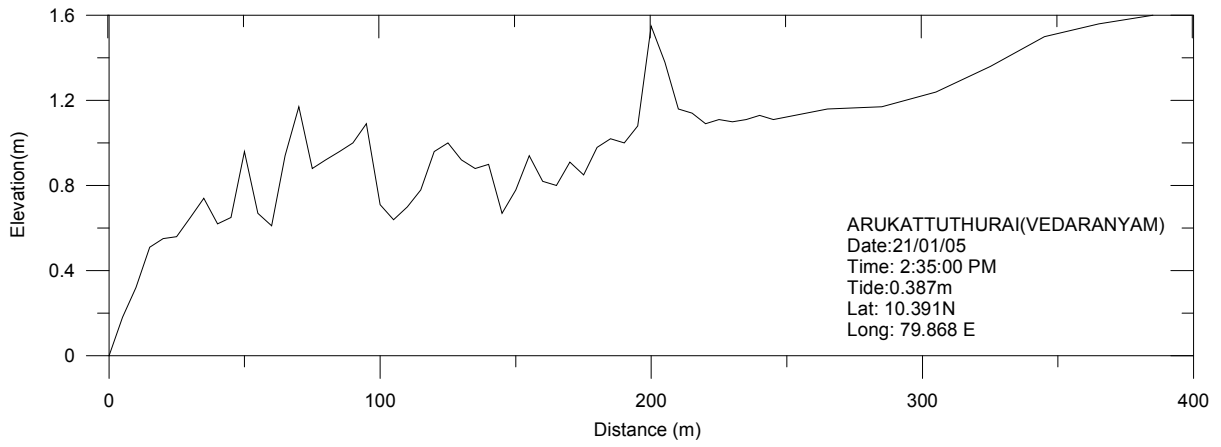


Fig. 5-1. Profiles of ground levels from water line along the run-up/inundation transect. Sites: Arukattuthurai , Velankanni (North) & Velankannai (Middle)

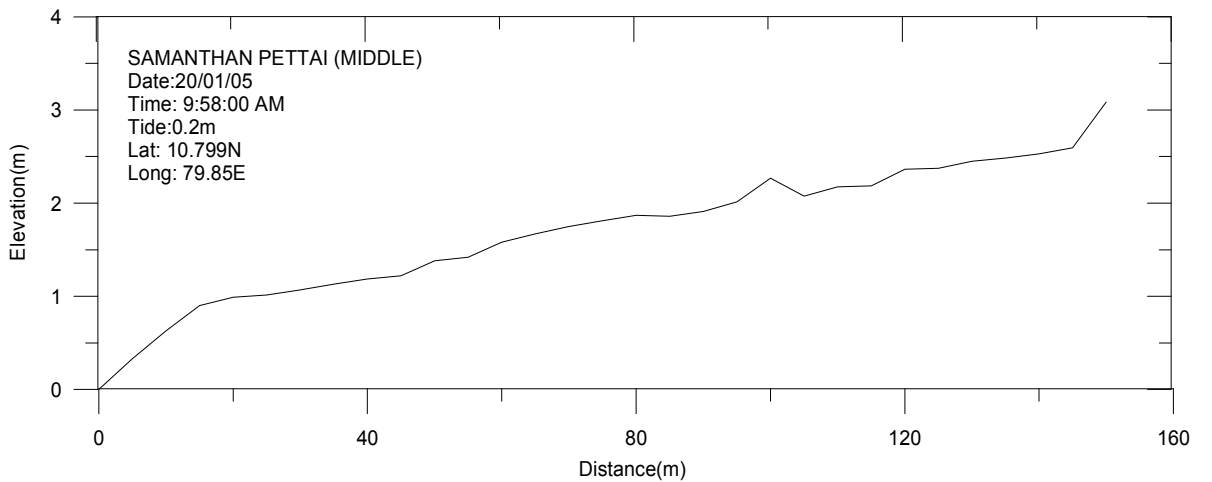
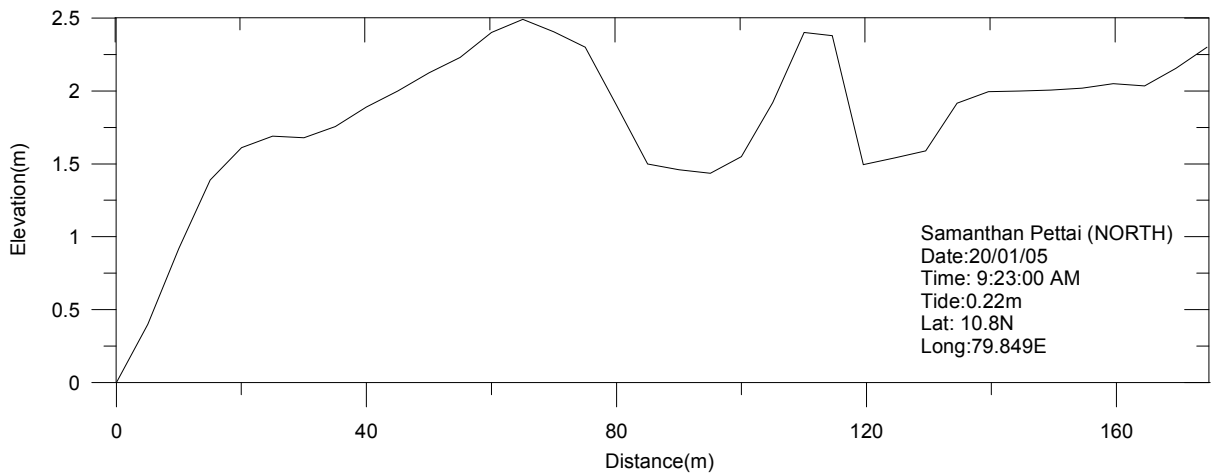
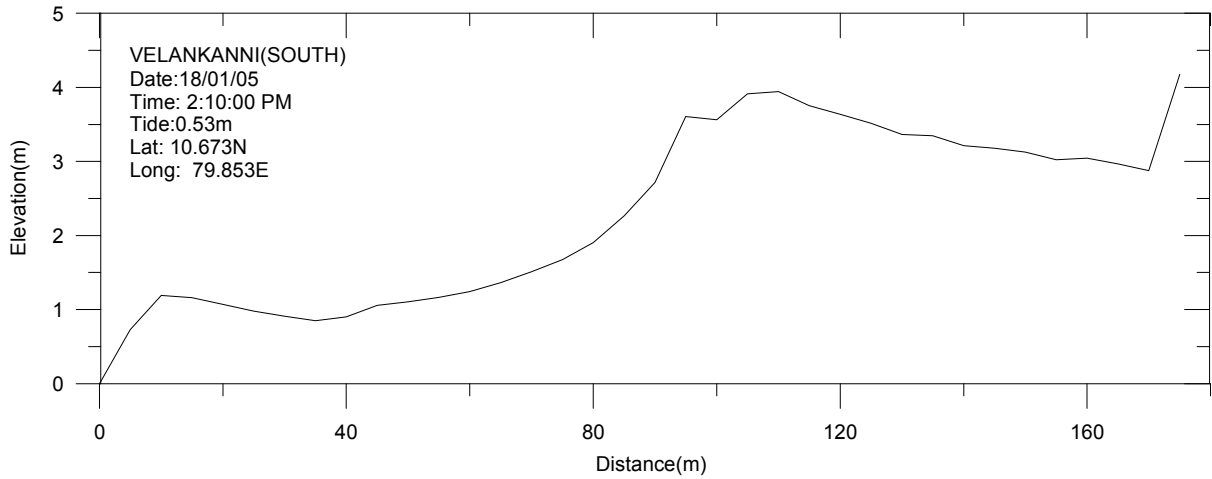


Fig. 5-2. Profiles of ground levels from waterline along the run-up/inundation transect. Sites: Velankanni (South), Samanthanpettai (North) & Samanthanpettai (Middle).

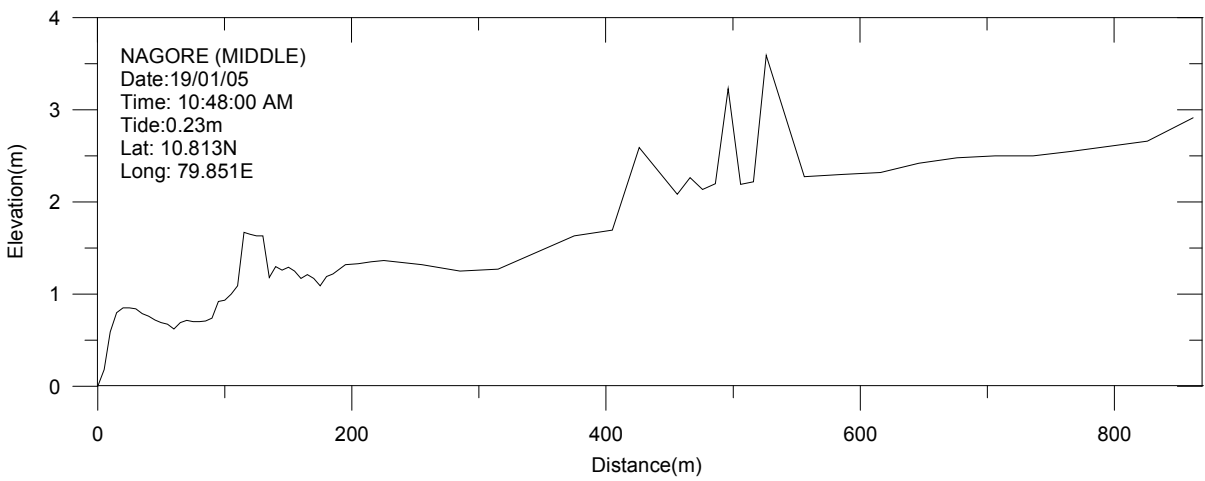
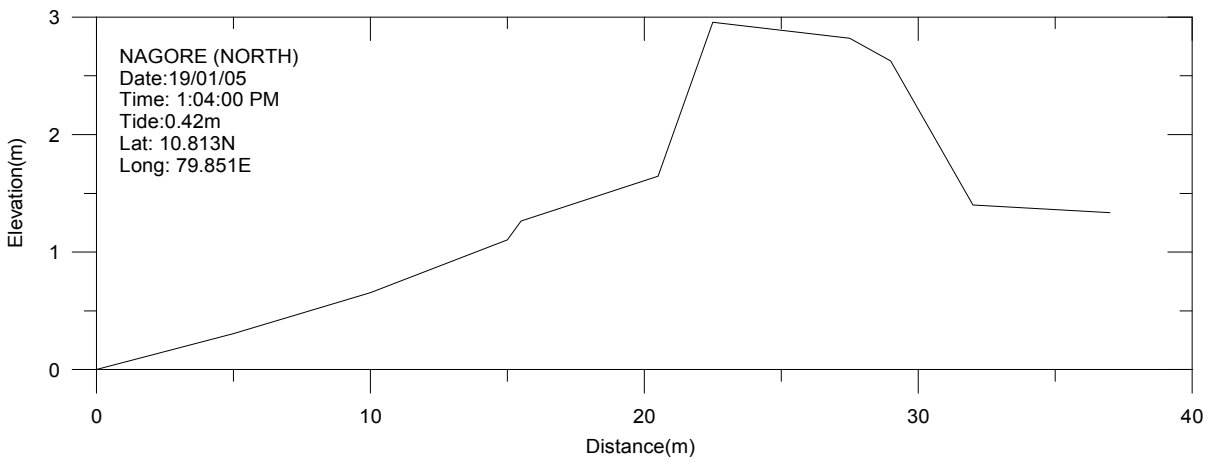
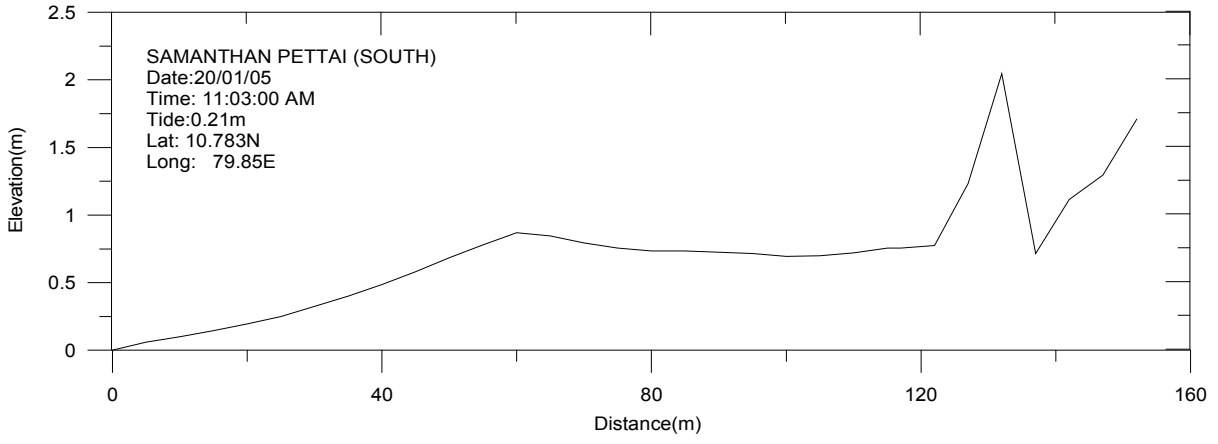


Fig. 5-3. Profiles of ground levels from waterline along the run-up/inundation transect. Sites: Samanthanpettai (South), Nagore (North) & Nagore (Middle).

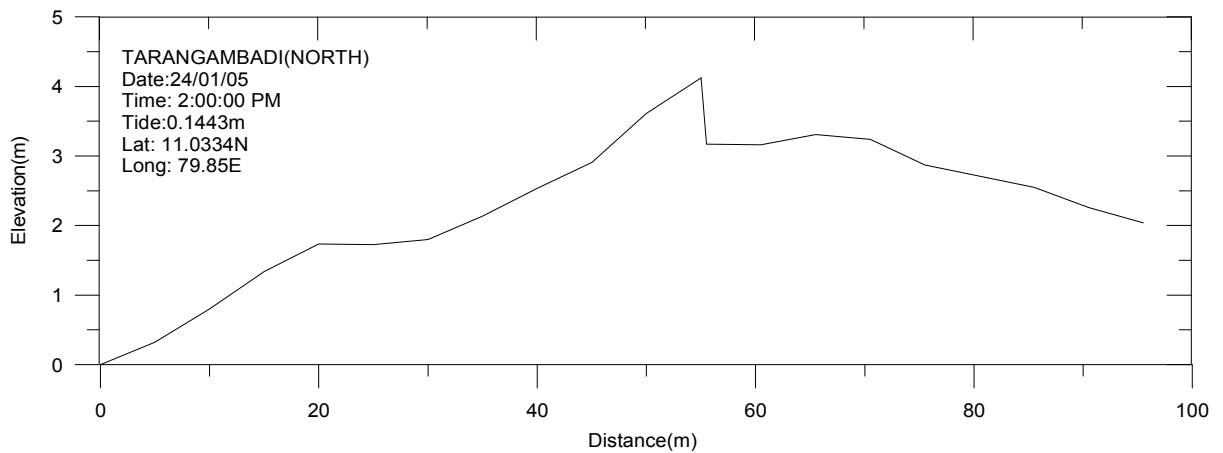
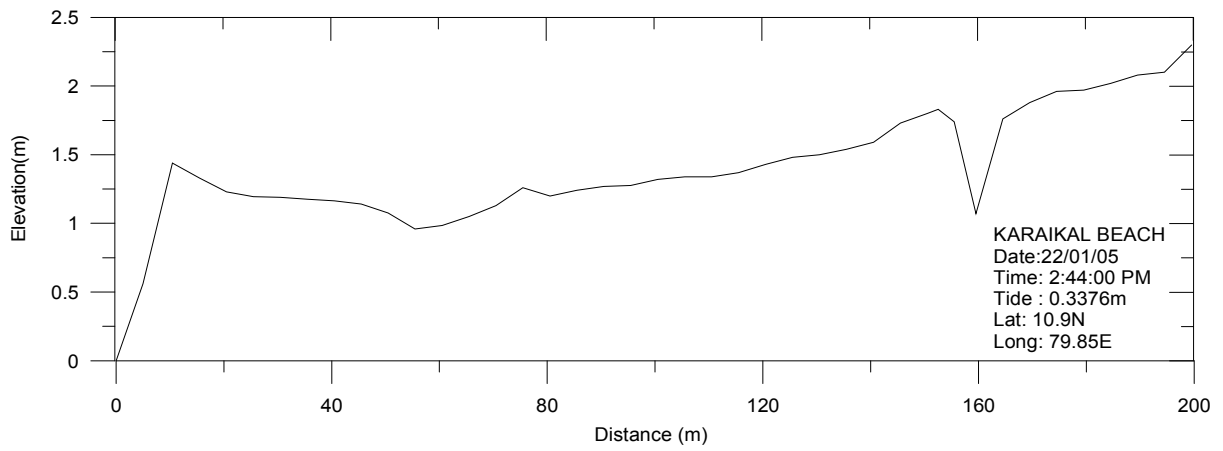
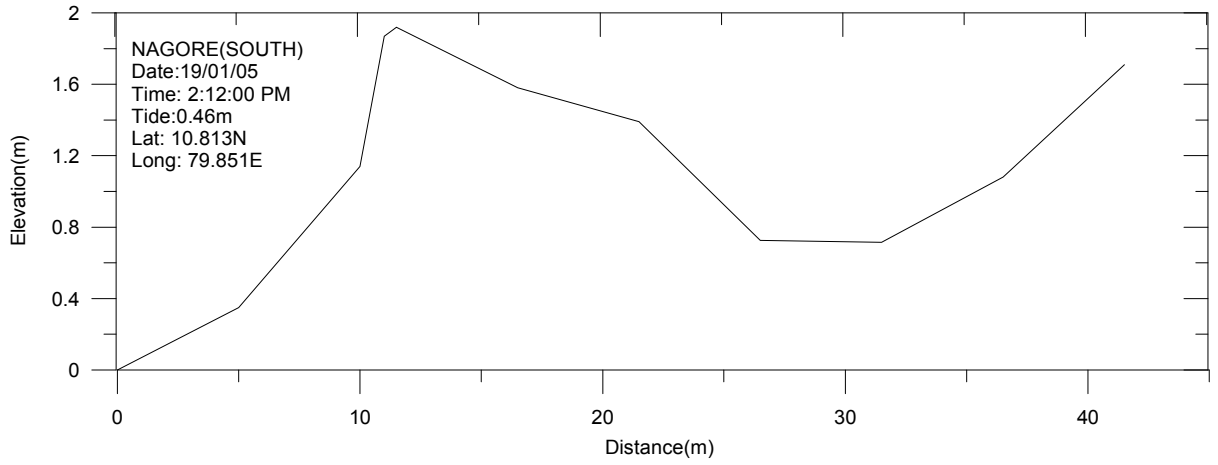


Fig. 5-4. Profiles of ground levels from waterline along the run-up/inundation transect. Sites: Nagore (South), Karaikal & Tarangambadi (North).

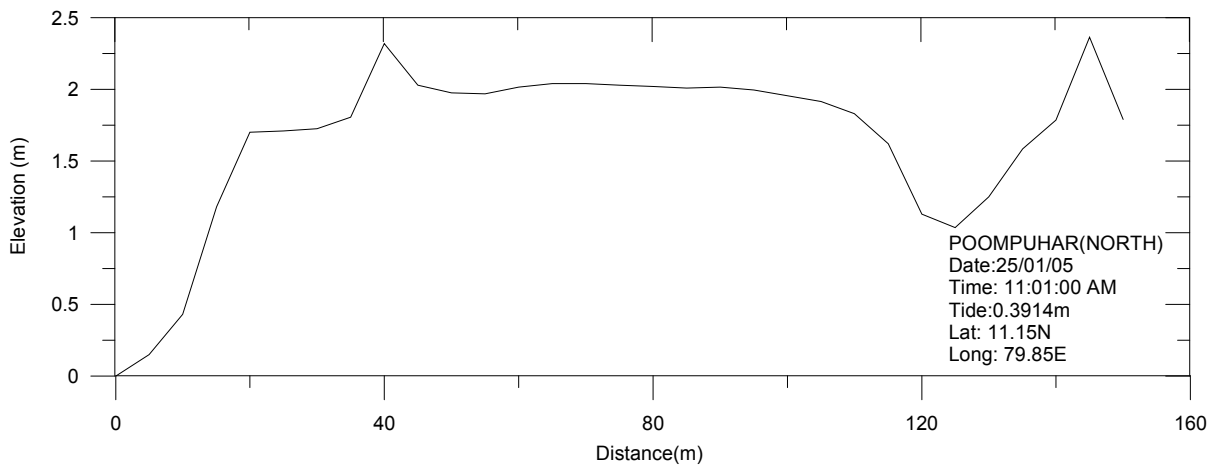
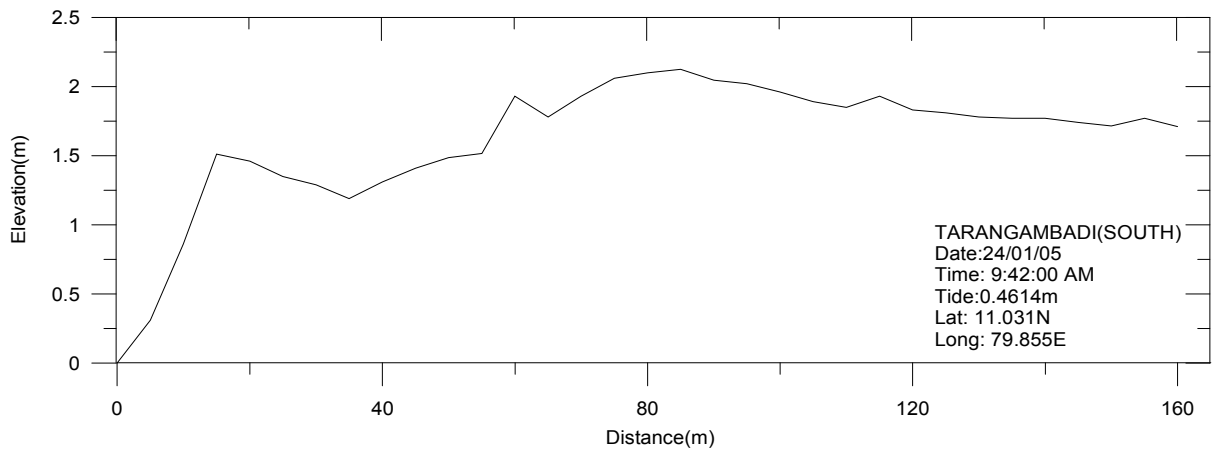
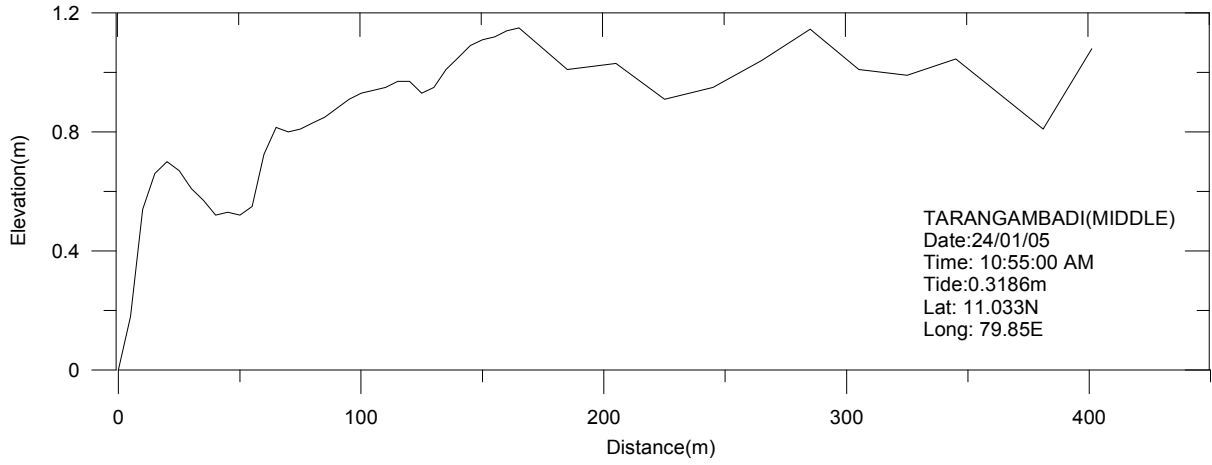


Fig. 5-5. Profiles of ground levels from waterline along the run-up/inundation transect. Sites: Tarangambadi (Middle), Tarangambadi (South) & Poompuhar (North).

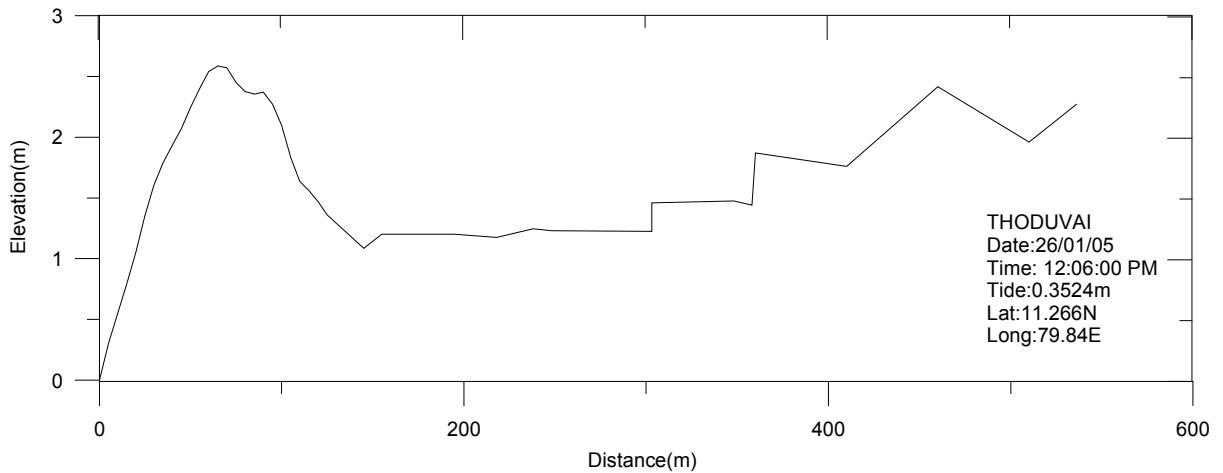
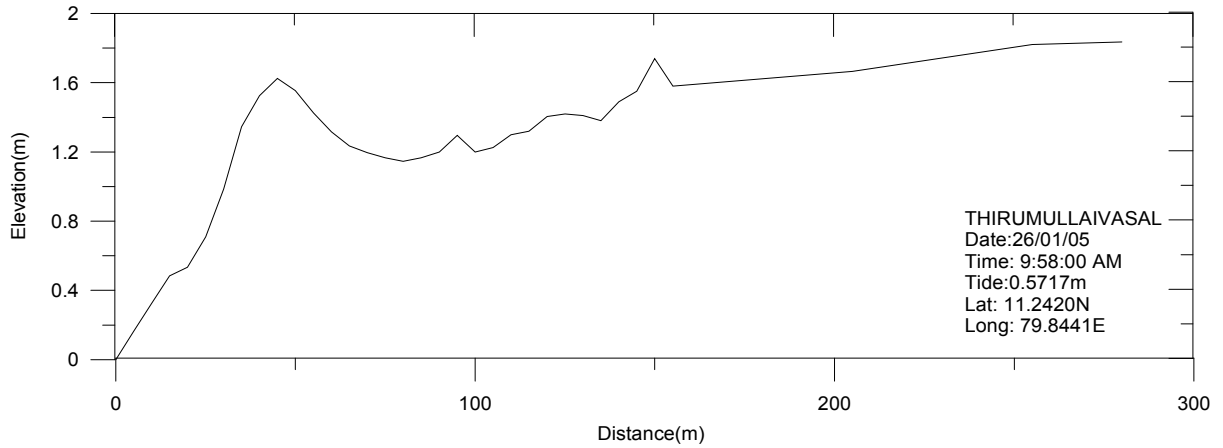
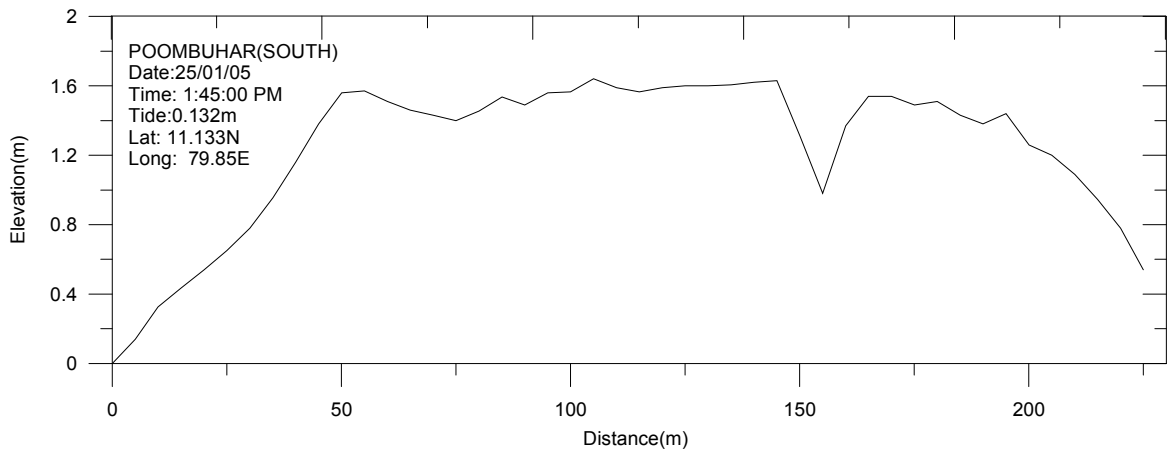


Fig. 5-6. Profiles of ground levels from waterline along the run-up/inundation transect. Sites:Poombuhar (South), Thirumullaivasal & Thoduvai.

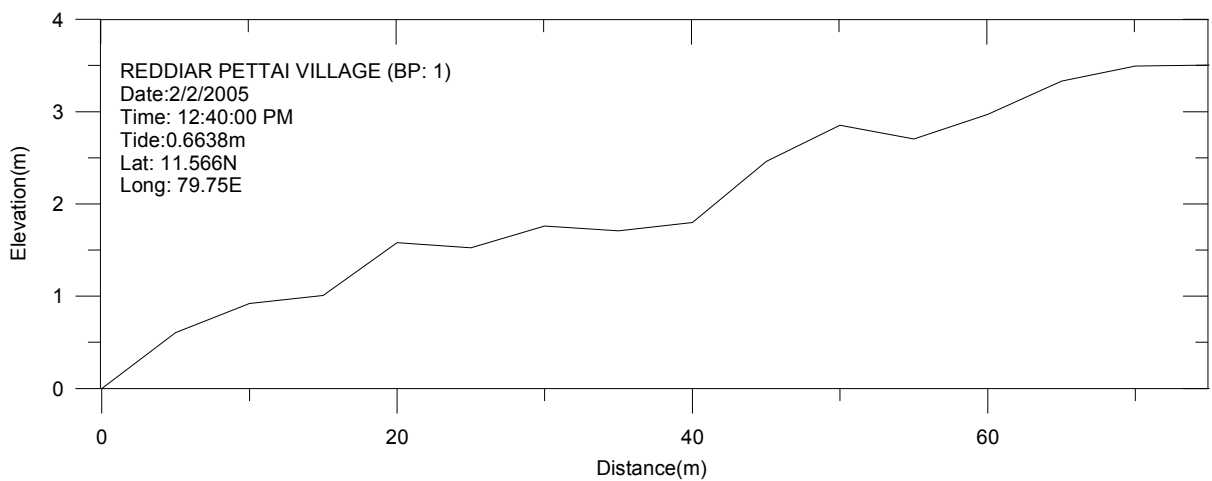
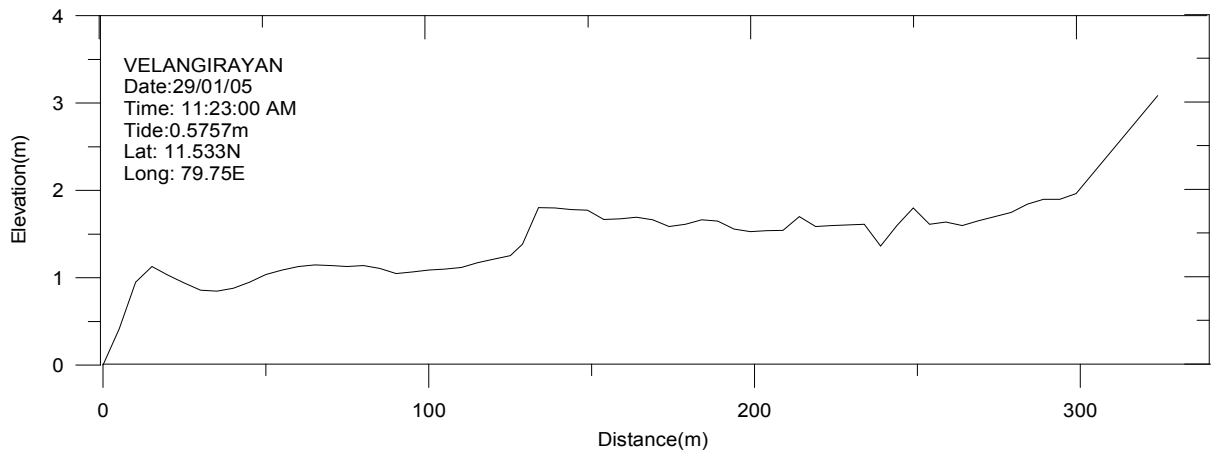
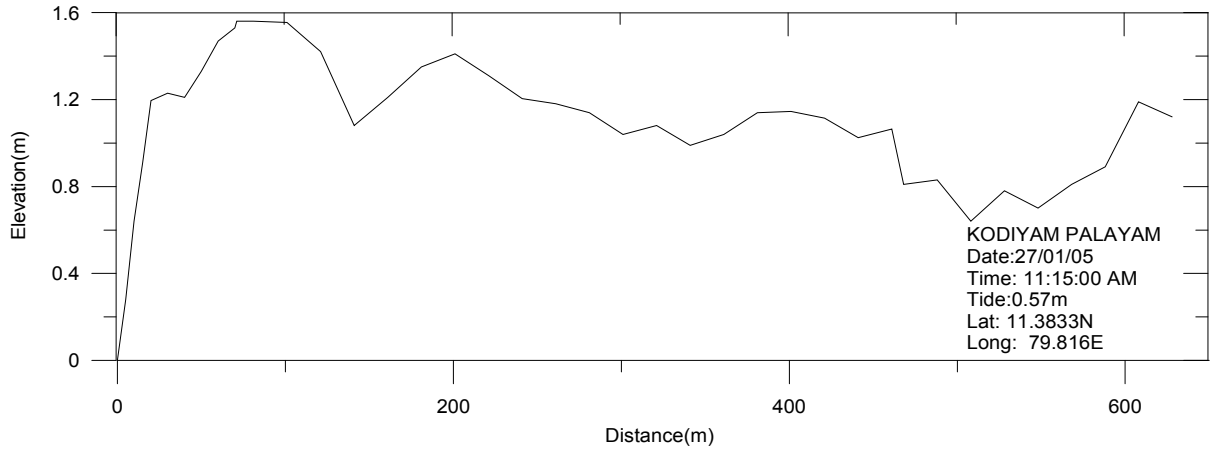


Fig. 5-7. Profiles of ground levels from waterline along the run-up/inundation transect. Sites: Kodiyaipalayam, Velangirayan & Reddiar Pettai - 1.

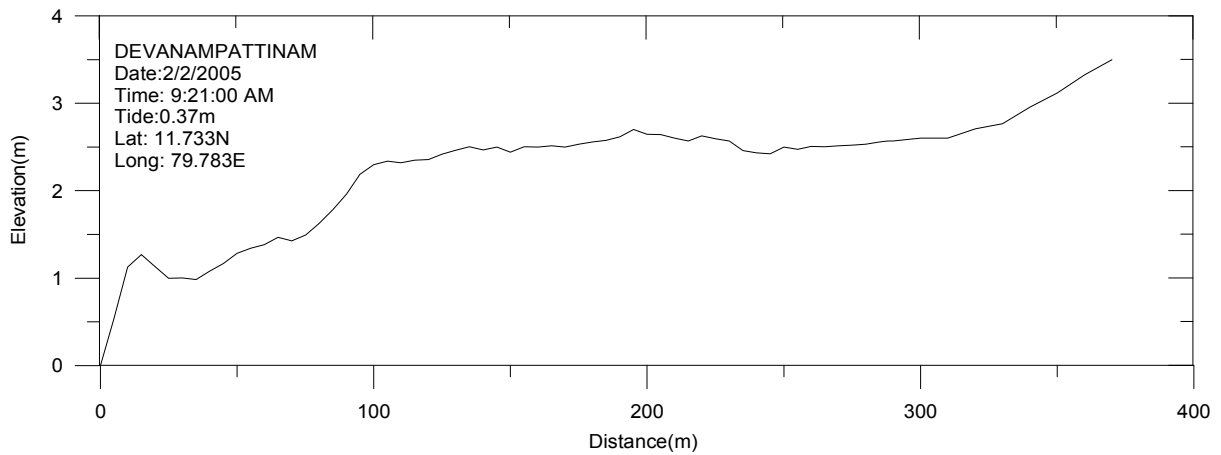
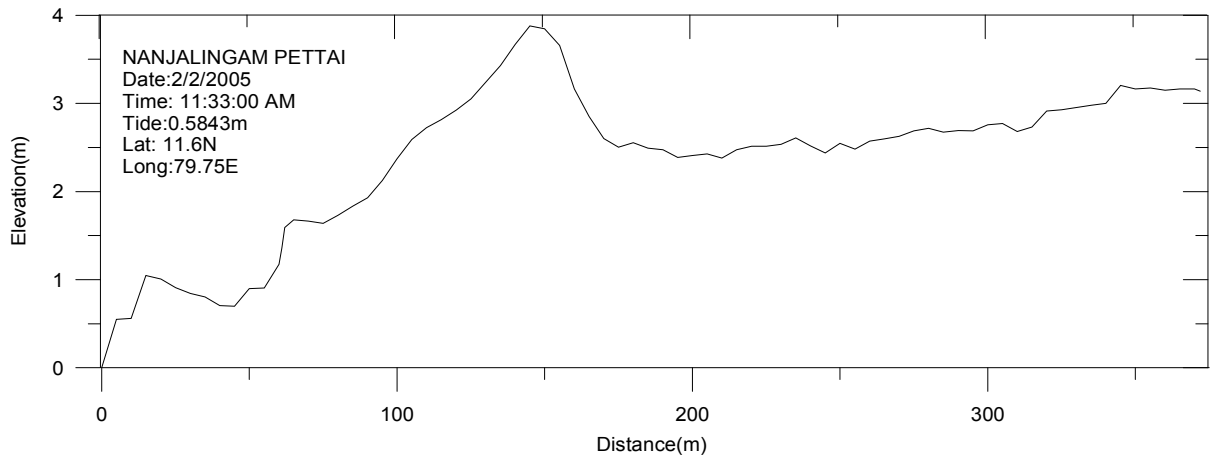
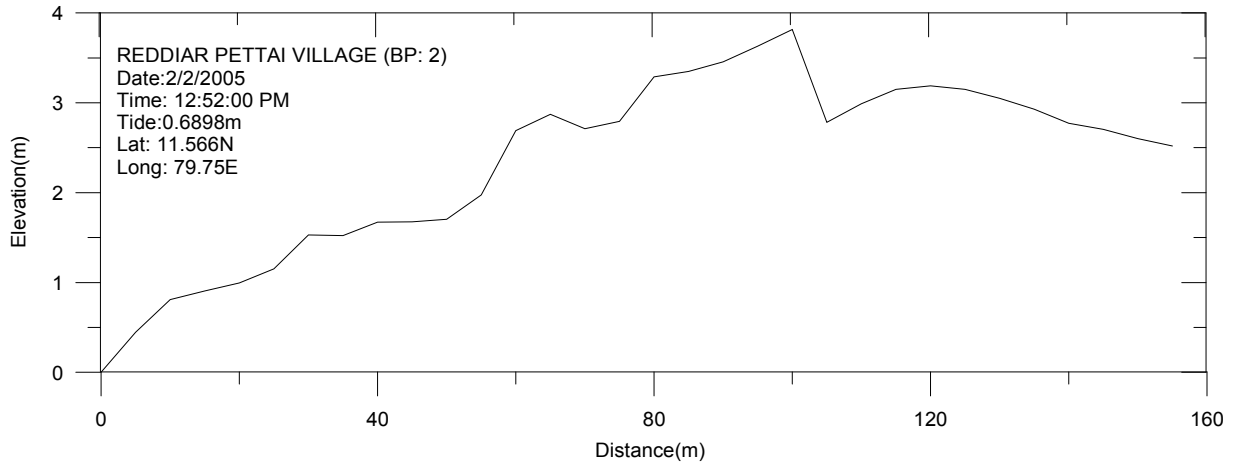


Fig. 5-8. Profiles of ground levels from waterline along the run-up/inundation transect. Sites: Reddiarpettai -2, Nanjalingampettai & Devanampattinam.

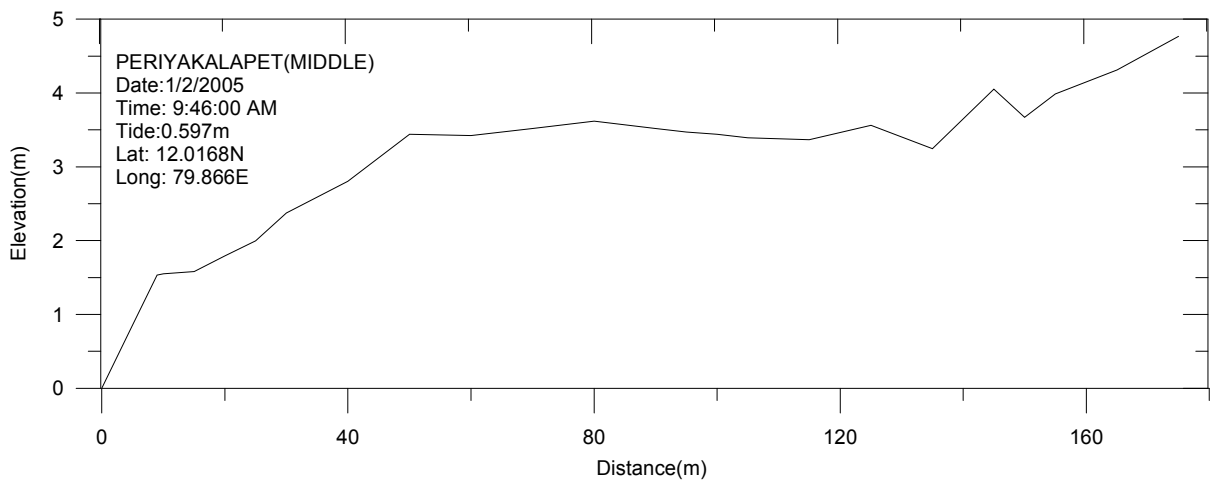
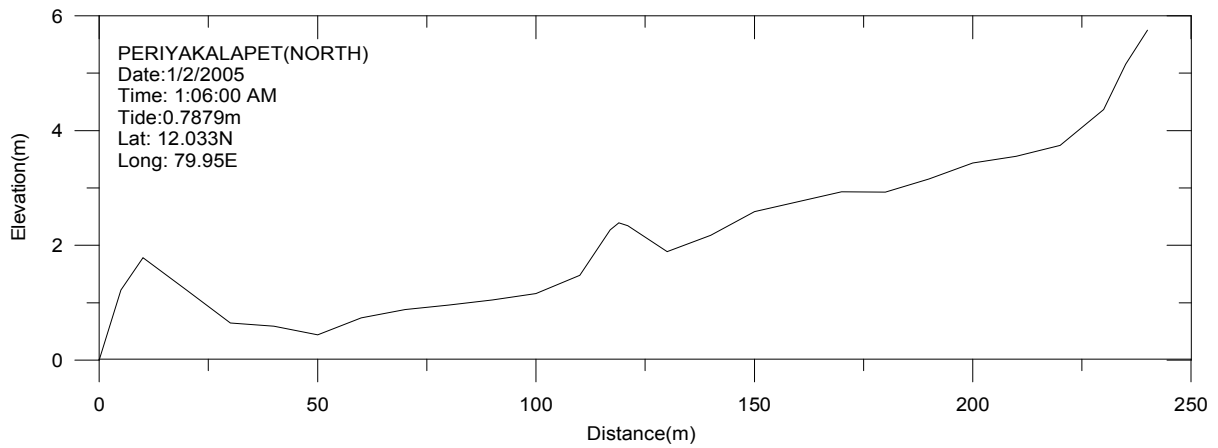
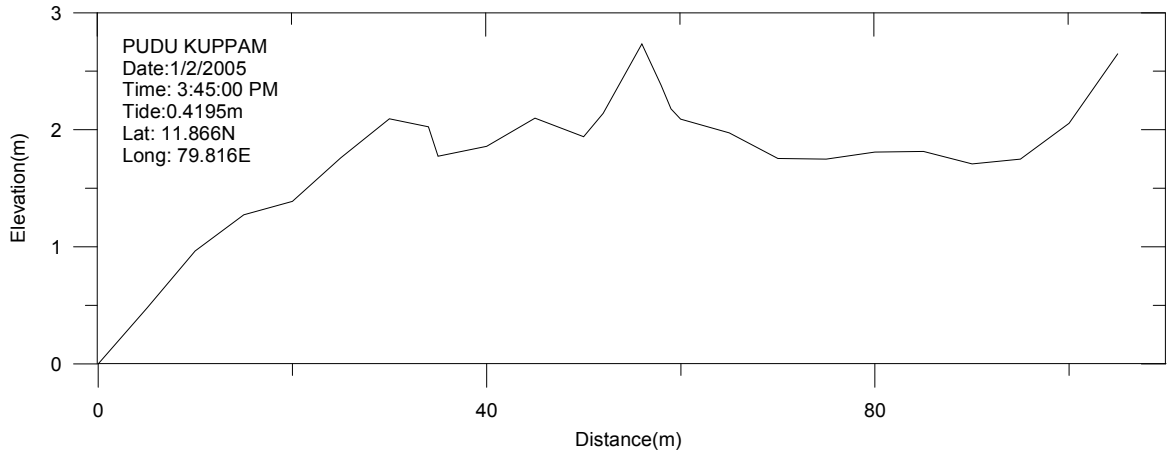


Fig. 5-9. Profiles of ground levels from waterline along the run-up/inundation transect. Sites: Pudukuppam, Periyakalapet (North) & Periyakalapet (Middle).

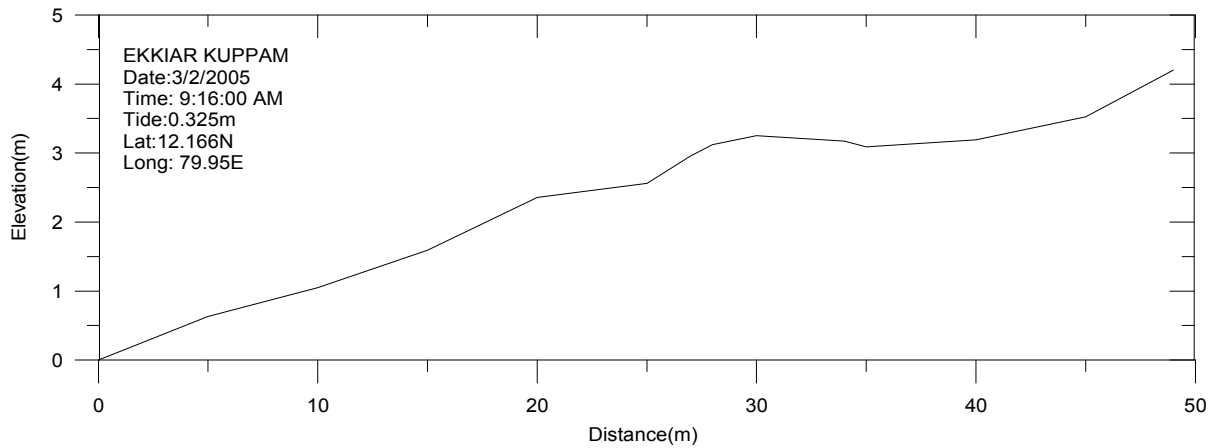
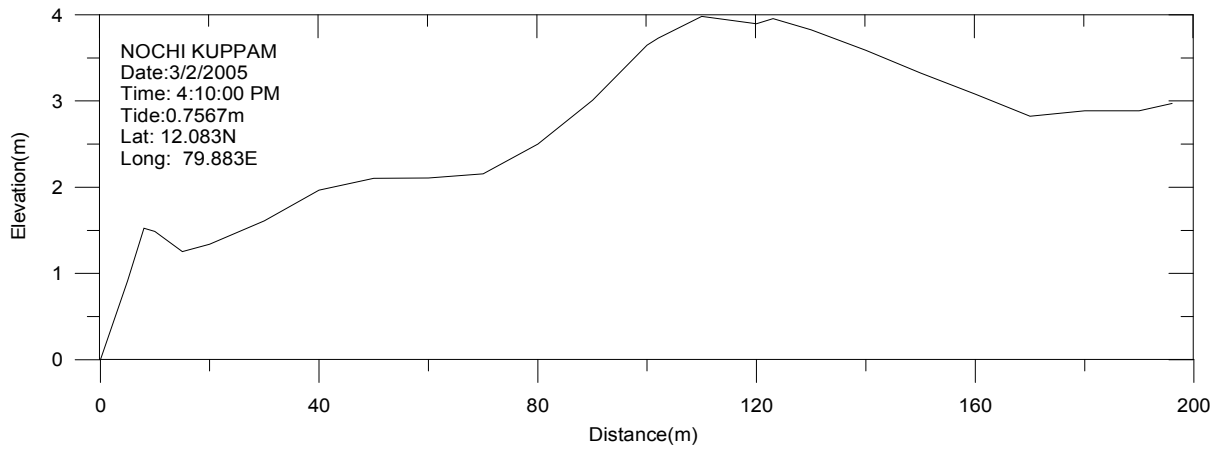
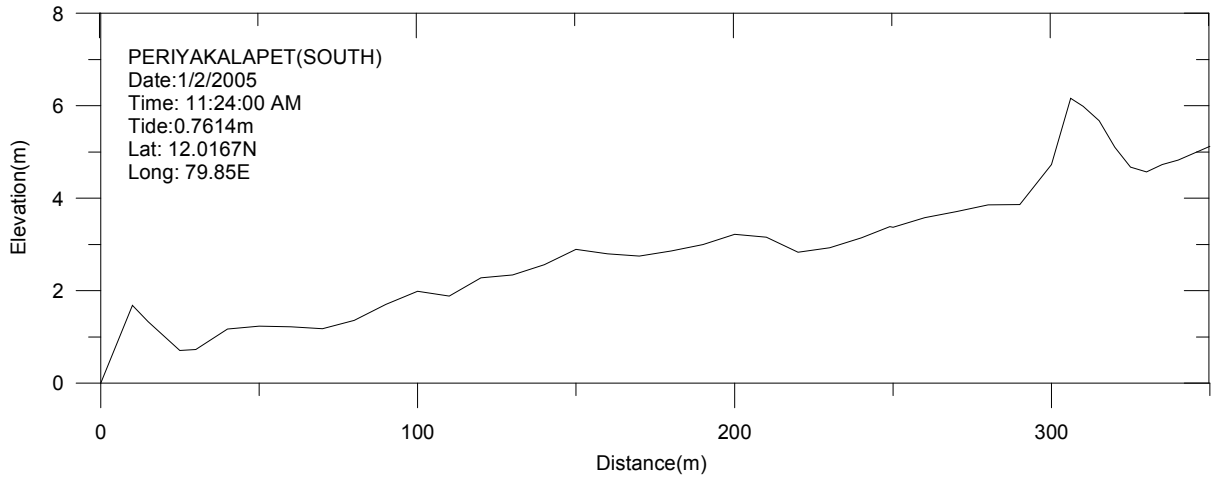


Fig. 5-10. Profiles of ground levels from waterline along the run-up/inundation transect. Sites: Periyakalapet (South), Nochikuppam & Ekkiarkuppam.

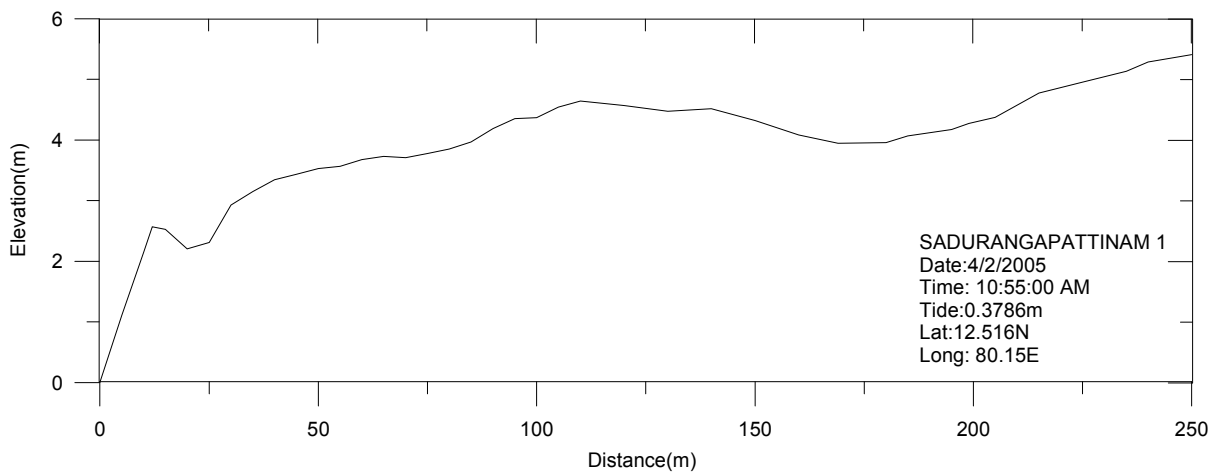
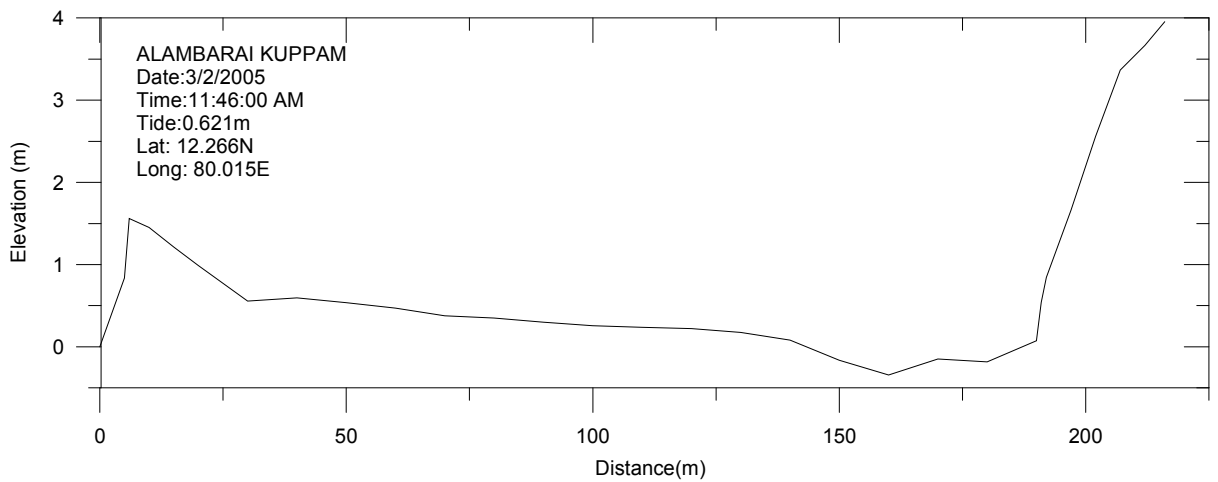
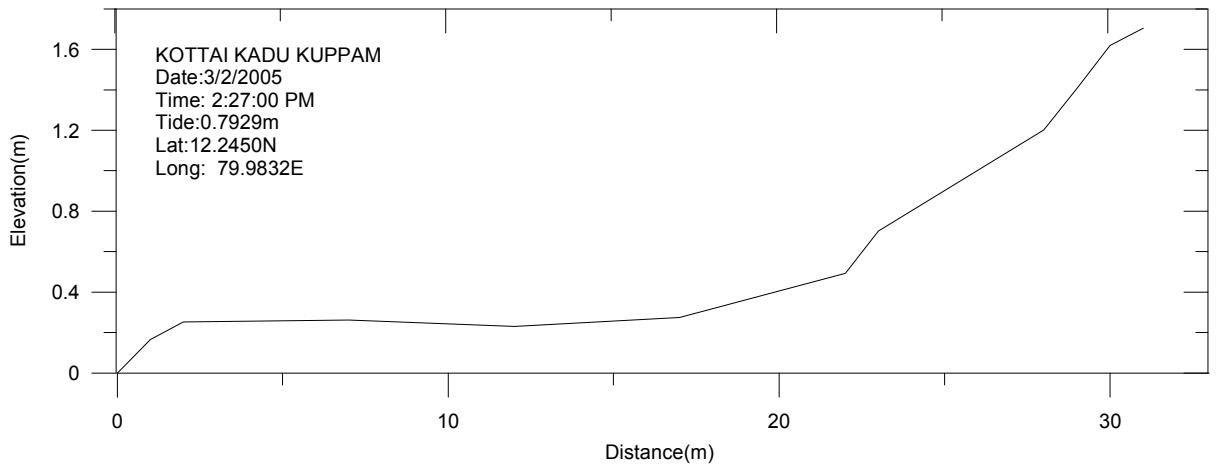


Fig. 5-11. Profiles of ground levels from waterline along the run-up/inundation transect. Sites: Kottaikadukuppam, Alambaraikuppam & Sadurangapattinam 1.

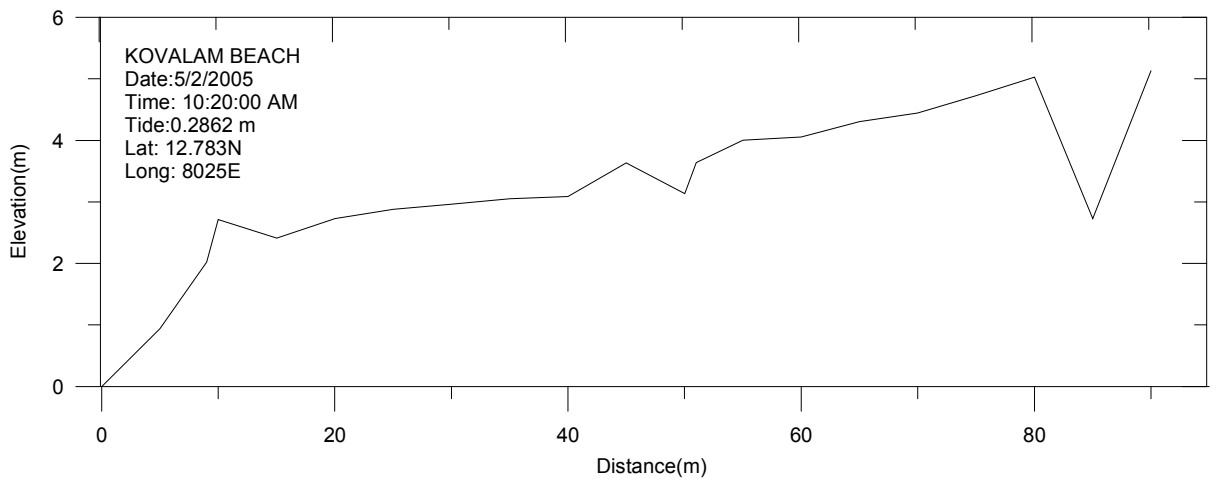
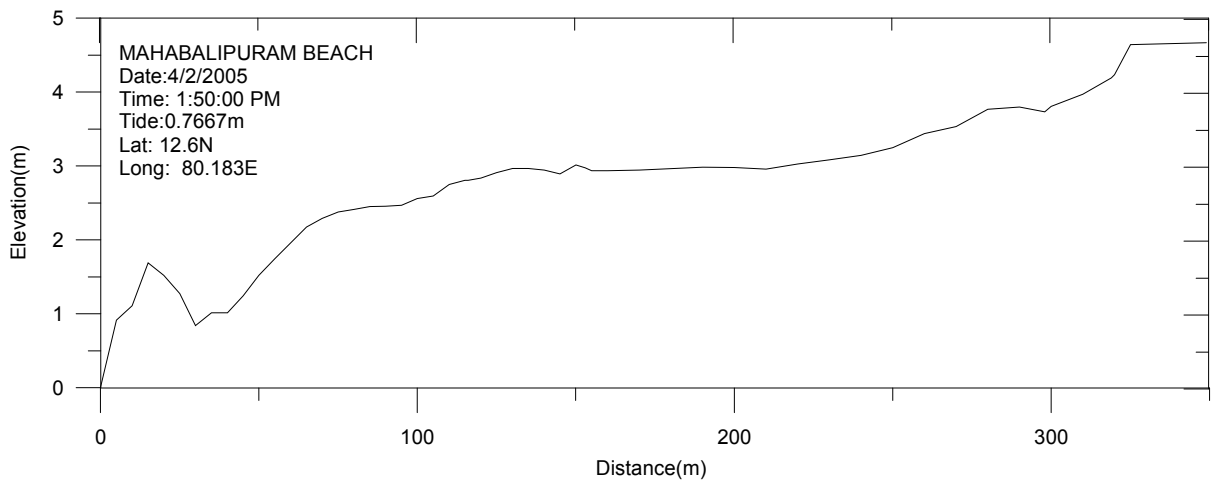
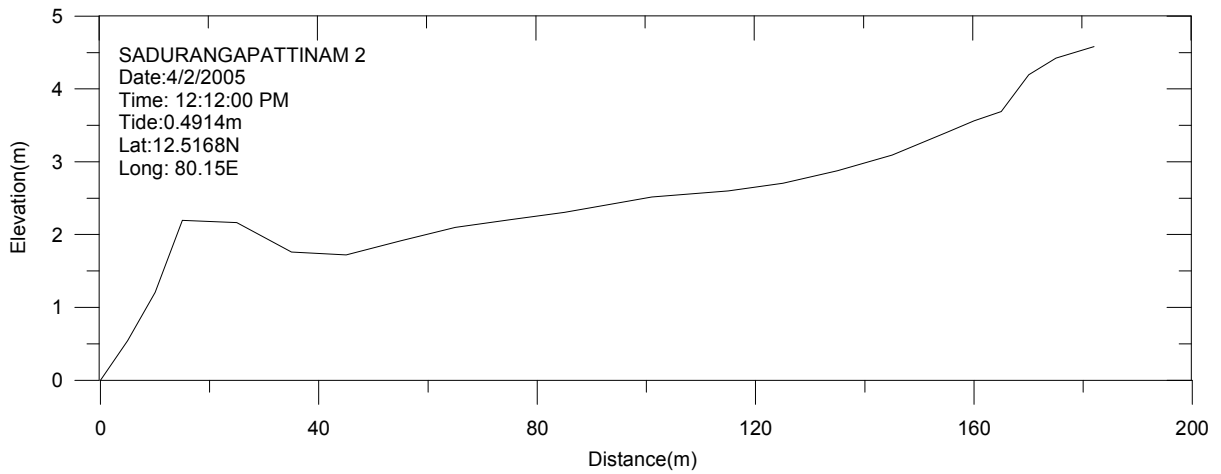


Fig. 5-12. Profiles of ground levels from waterline along the run-up/inundation transect. Sites: Sadurangapattinam-2, Mahabalipuram Beach & Kovalam Beach.

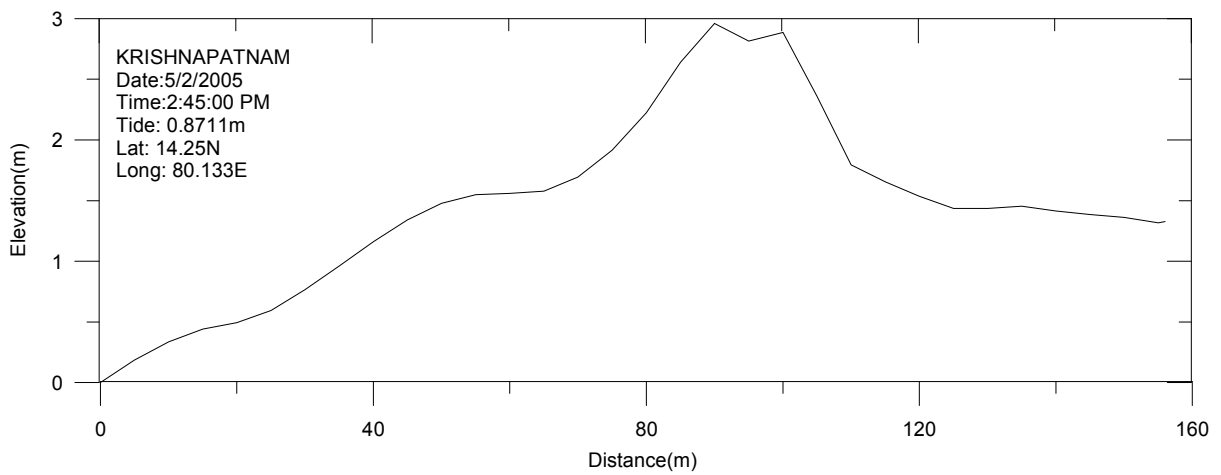
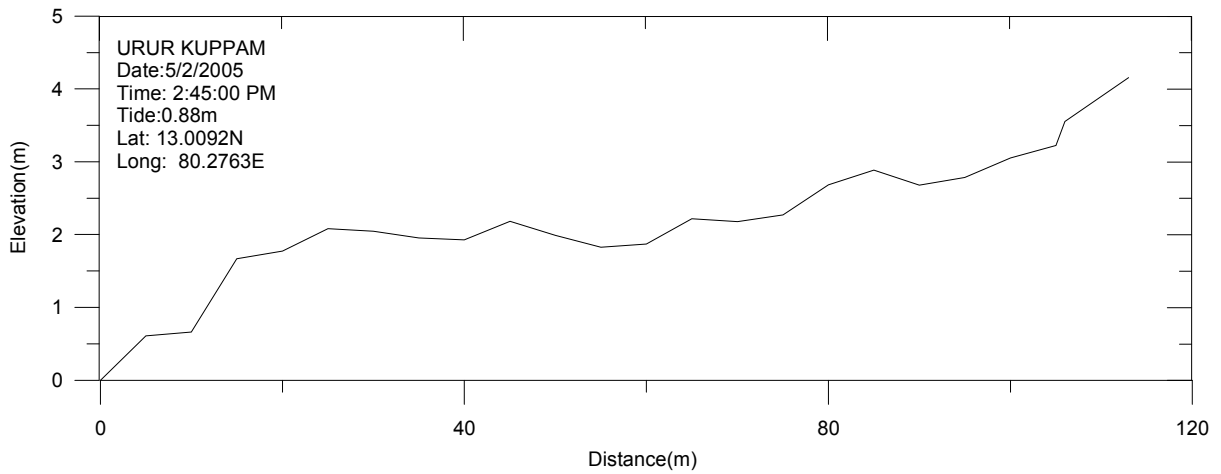


Fig. 5-13. Profiles of ground levels from waterline along the run-up/inundation transect. Sites: Urur Kuppam & Krishnapatnam.

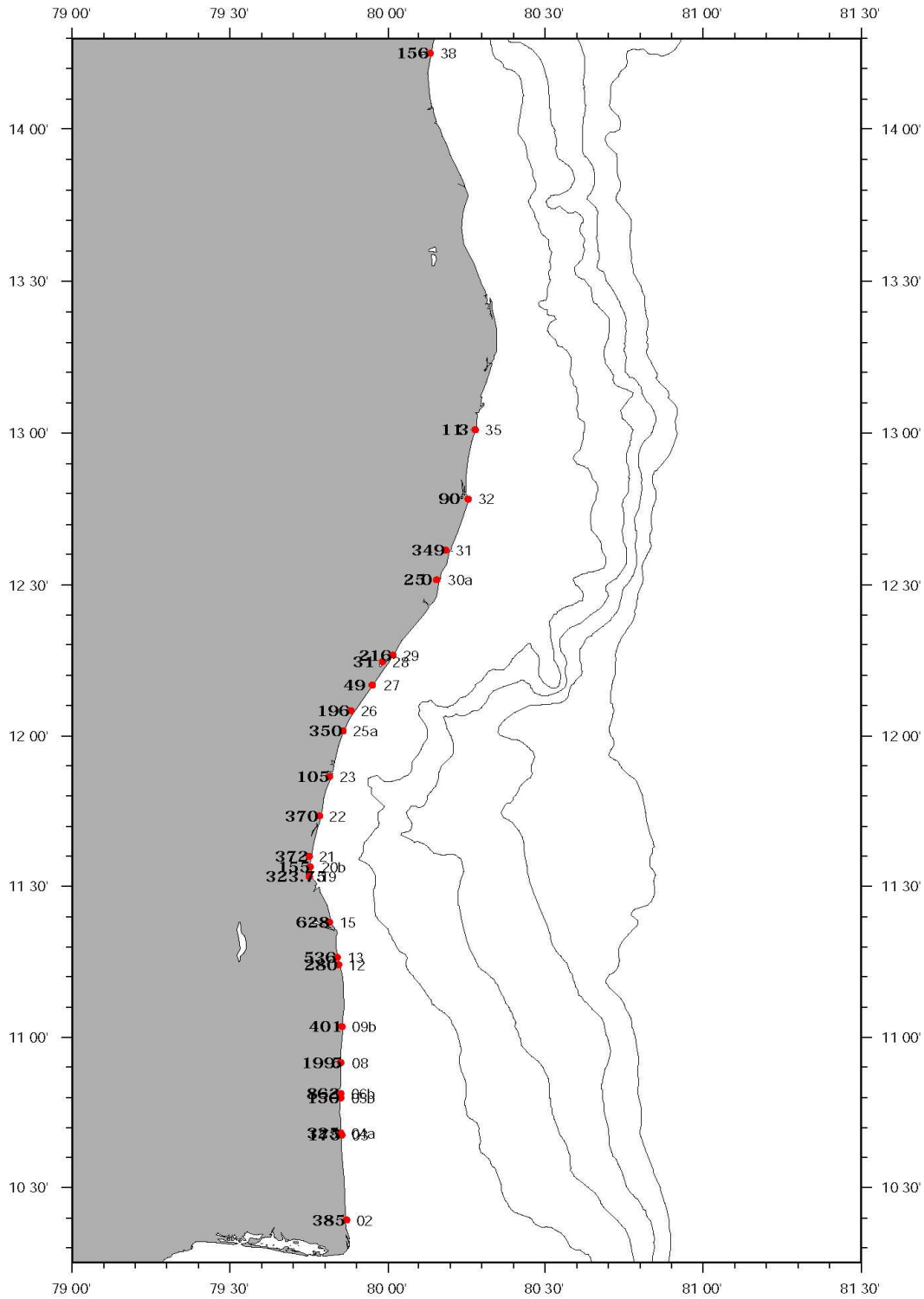


Fig. 6. Map showing observed tsunami inundation limits at various sites. Red dots show the sites, numbers right to the dots show site ID and left to the dots show inundation limit (in 'm'). Further details are given in Table. 2

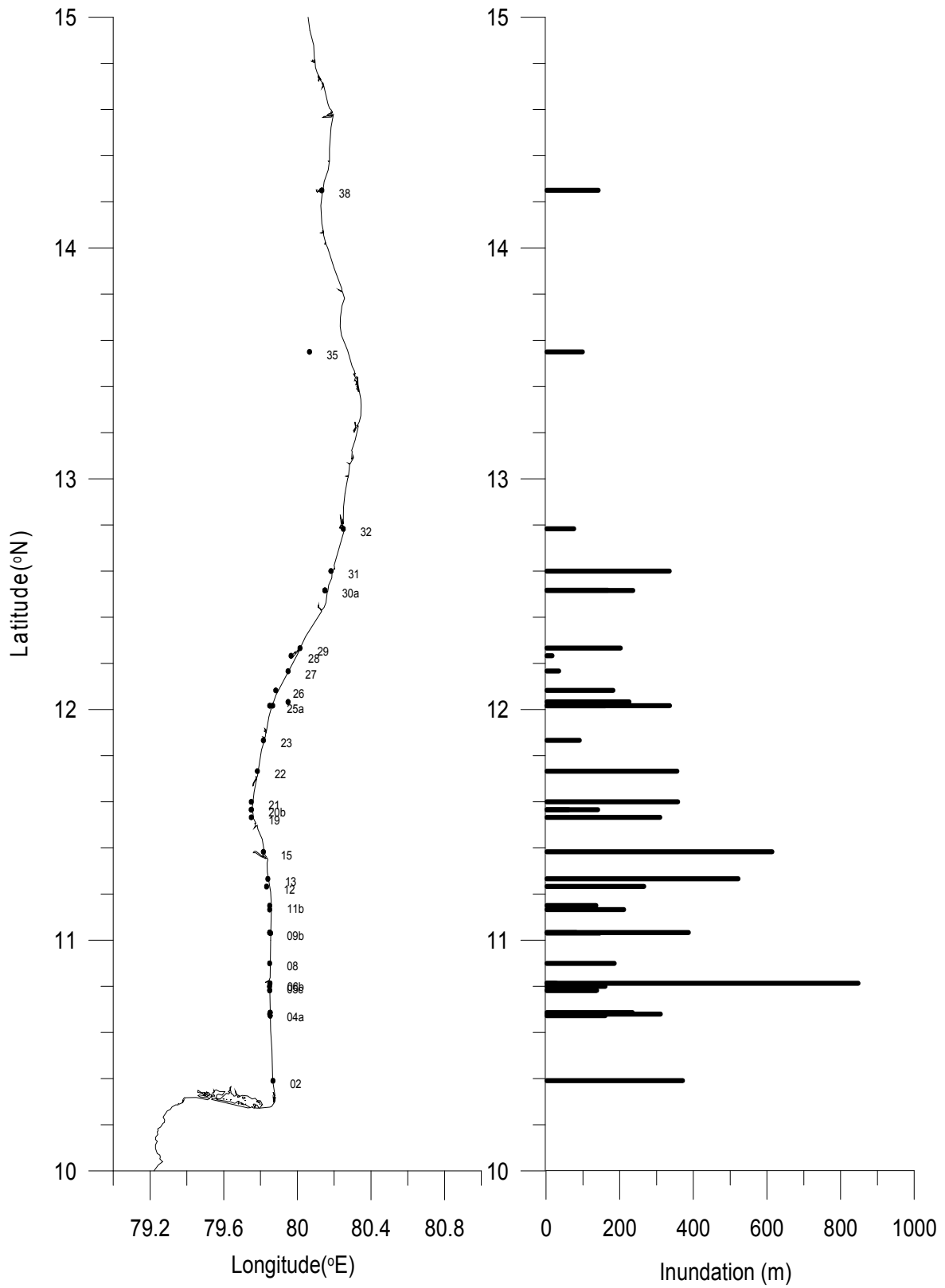


Fig. 7. Bar graph (right panel) depicting the variation of tsunami inundation limit at various sites (left panel). Further details are given in Table 2.

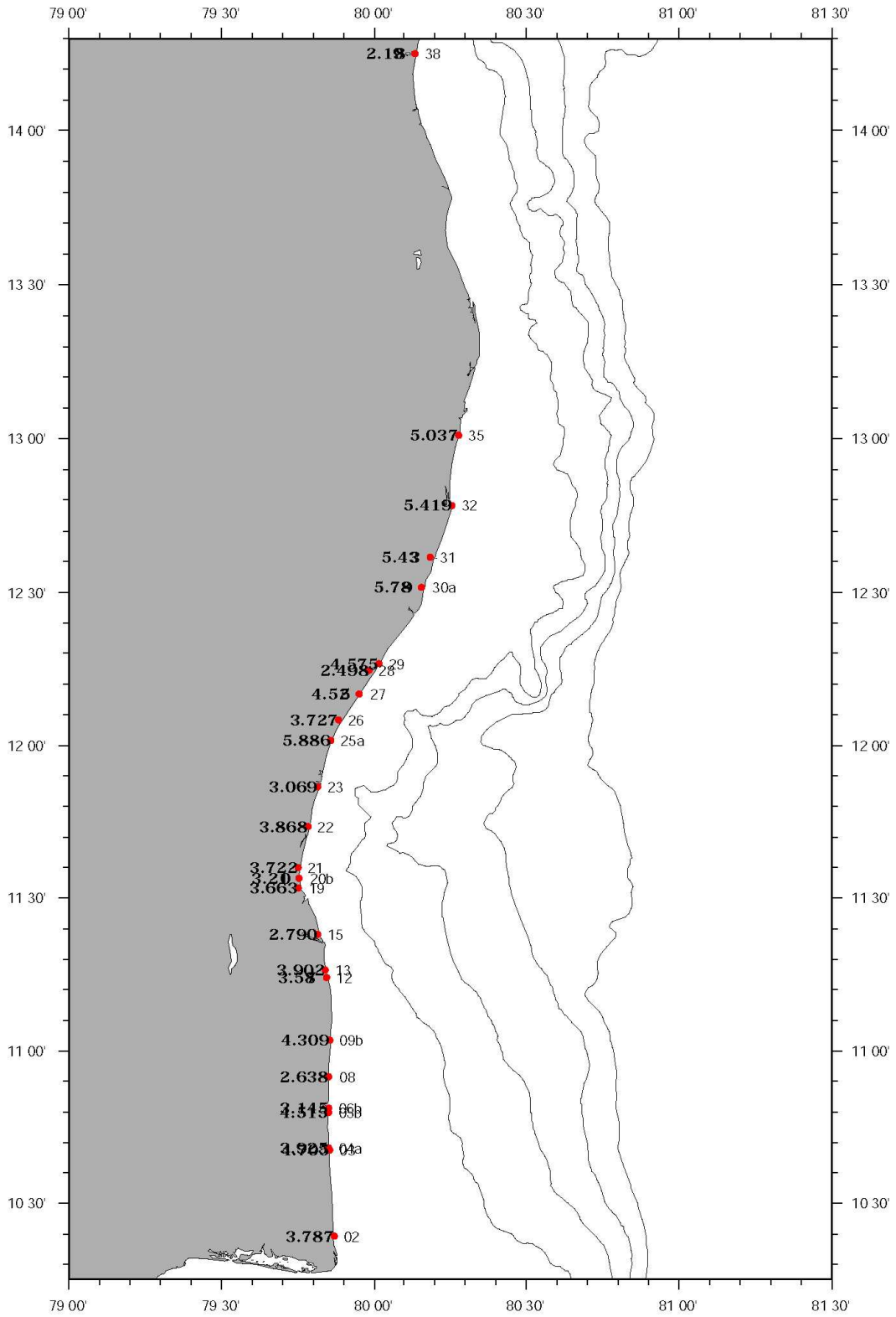


Fig. 8. Map showing observed tsunami run-up heights at various sites. Red dots show the sites, numbers right to the dots show site ID and left to the dots show run-up heights (in 'm'). Further details are given in Table 2.

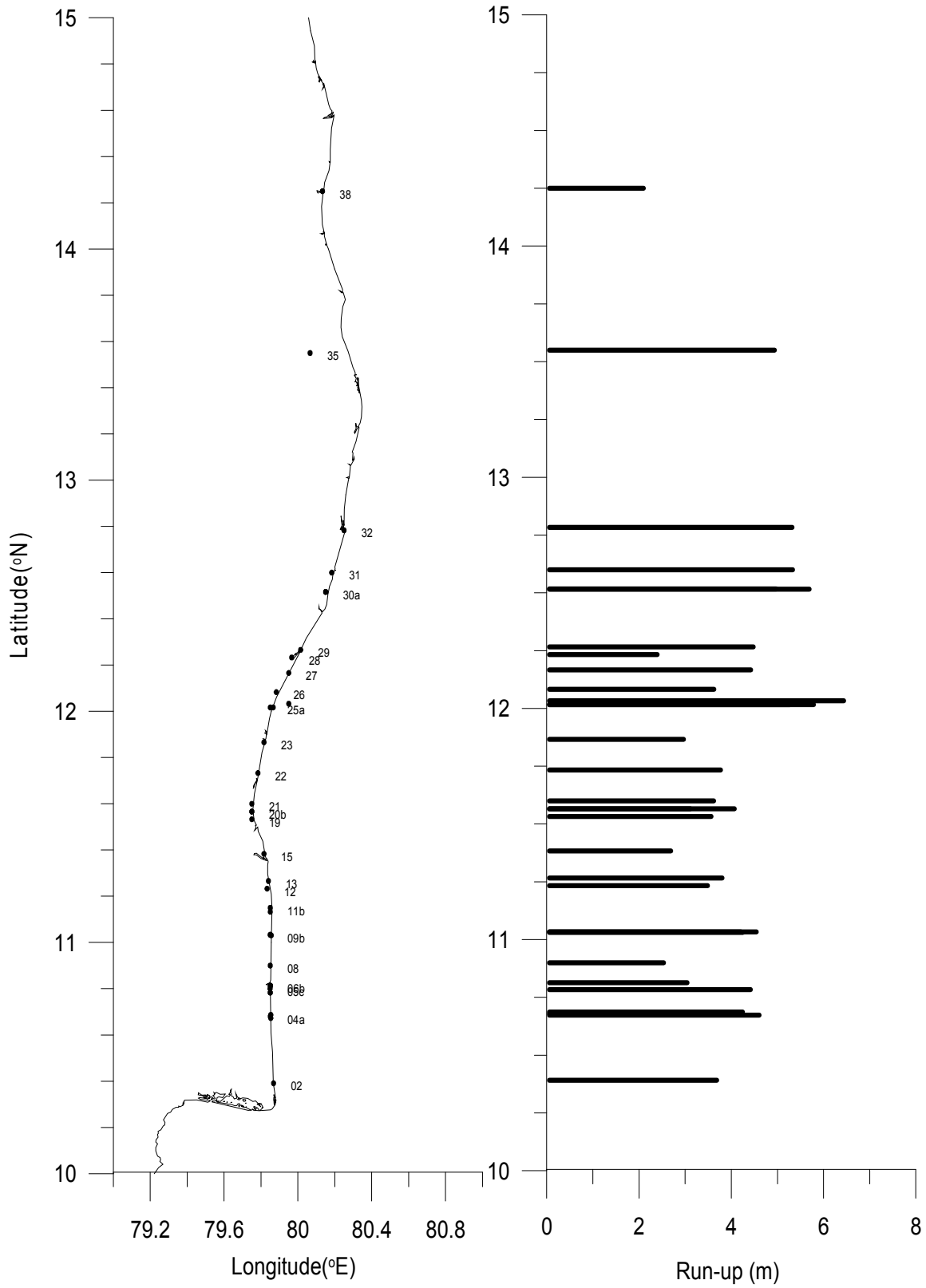


Fig. 9. Bar graph (right panel) depicting the variation of tsunami run-up at various sites (left panel). Further details are given in Table 2.

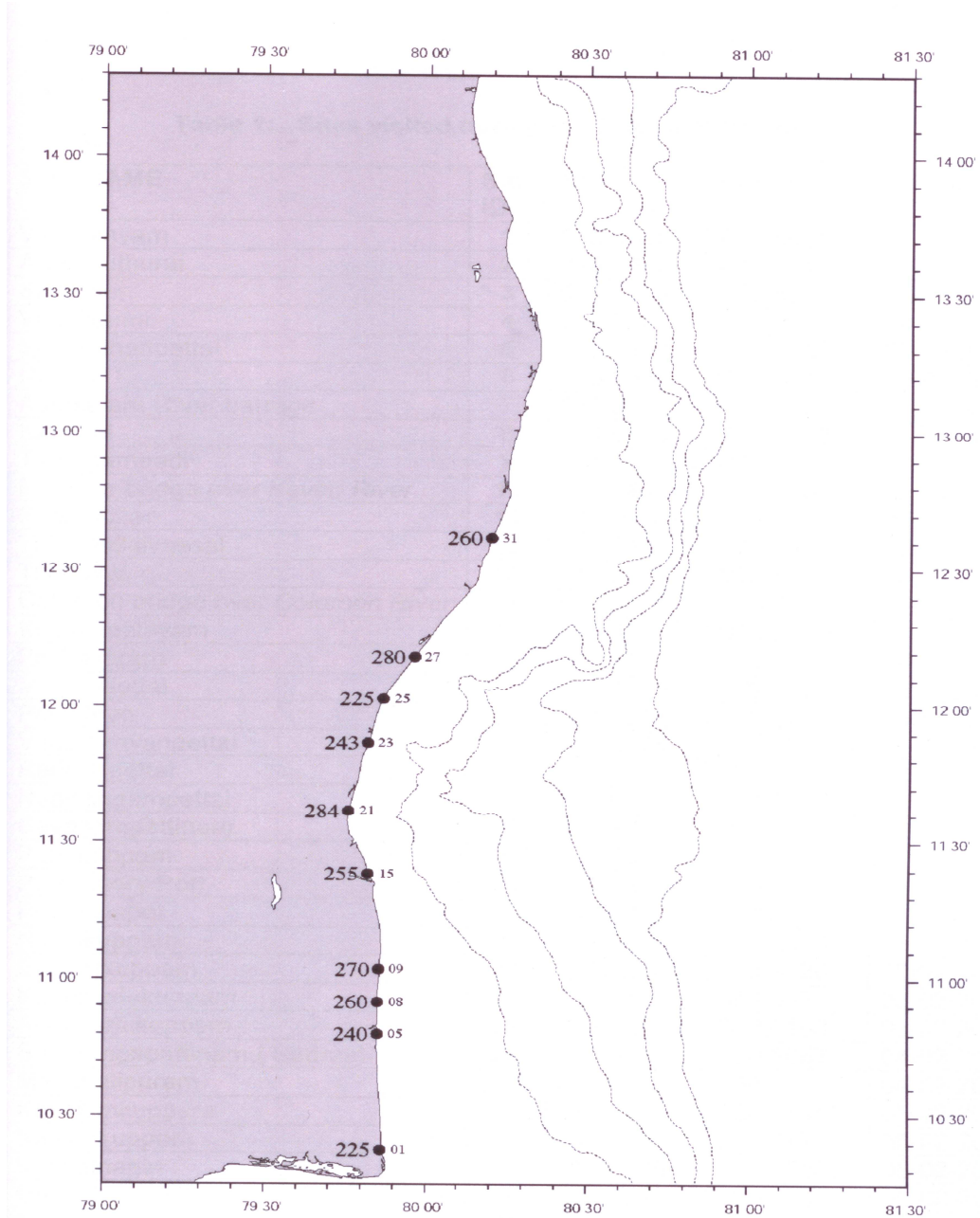


Fig. 10. Map showing inferred tsunami bearing at various sites. Black dots show the sites, numbers right to the dots show site ID and left to the dots show inferred tsunami bearing (in degrees). Further details are given in Table 3.

Table 1: Sites visited during the field programme

SITE NAME	Site ID	Latitude	Longitude	Date of visit
Vedaranyam	1	010.3745	079.8639	21-01-2005
Arukattuthurai	2	010.3935	079.8687	21-01-2005
Serudhur	3	010.6736	079.8535	18-01-2005
Velankanni	4	010.6802	079.8506	18-01-2005
Samanthanpettai	5	010.7993	079.8509	20-01-2005
Nagore	6	010.8132	079.8512	19-01-2005
Aarasalaru River barrage	7	010.9102	079.8183	22-01-2005
Karaikal	8	010.9140	079.8523	22-01-2005
Tarangampadi	9	011.0361	079.8553	24-01-2005
Melaiyur bridge over <i>Kaveri River</i>	10	011.1455	079.8191	25-01-2005
Poompuhar	11	011.1500	079.8574	25-01-2005
Thirumullaivassal	12	011.2420	079.8441	26-01-2005
Thoduvai	13	011.2732	079.8408	26-01-2005
Coleroon bridge over <i>Coleroon River</i>	14	011.3386	079.7104	28-01-2005
Kodiampalayam	15	011.3857	079.8209	27-01-2005
Pitchavaram	16	011.4296	079.7811	28-01-2005
Mudasalodai	17	011.4750	079.7708	28-01-2005
Port Novo	18	011.5018	079.7721	29-01-2005
Velangirayanpettai	19	011.5375	079.7624	29-01-2005
Reddiarpettai	20	011.5762	079.7562	02-02-2005
Nanjalingampettai	21	011.6129	079.7597	02-02-2005
Devanampattinam	22	011.7457	079.7846	02-02-2005
Pudukuppam	23	011.8657	079.8183	01-02-2005
Pondichery Port	24	011.9229	079.8340	29-01-2005
Periakalpet	25	012.0283	079.8674	01-02-2005
Nochikuppam	26	012.0880	079.8996	03-02-2005
Ekkiyarkuppam	27	012.1824	079.9620	03-02-2005
Kottaikadukuppam	28	012.2450	079.9832	03-02-2005
Alambaraikuppam	29	012.2680	080.0153	03-02-2005
Sadurangapattinam (Sadras)	30	012.5235	080.1657	04-02-2005
Mahabalipuram	31	012.6154	080.1991	04-02-2005
Kovalamkuppam	32	012.7889	080.2545	05-02-2005
Karikatkuppam	33	012.8324	080.2477	05-02-2005
Vesantnagar	34	012.9975	080.2726	05-02-2005
Urur Alcottkuppam	35	013.0098	080.2763	05-02-2005
Narrarthottam	36	013.1285	080.2980	05-02-2005
Beemarupalayamkuppam	37	013.5541	080.0770	06-02-2005
Krishnapattanam	38	014.2500	080.1379	06-02-2005

Table 2. Inundation limit, run-up height & other related information at different sites.

Sr. No.	Station Name	Date	Time	Tide (m)	Position		Inundation Limit (m)	Run up (w.r.t. CD) (m)
					Latitude	Longitude		
1	Arukattuthurai	21/01/05	1435	0.387	10.391	79.868	385	3.787
2	Velankanni (South)	18/01/05	1410	0.530	10.673	79.853	175	4.705
3	Velangani (Middle)	18/01/05	0954	0.230	10.68	79.85	325	3.925
4	Velangani (North)	18/01/05	1020	0.250	10.687	79.853	249	4.345
5	Samanthan Pettai (South)	20/01/05	1103	0.210	10.783	79.85	152*	NA
6	Samanthan Pettai (Mid)	20/01/05	0958	0.200	10.783	79.85	150*	4.515*
7	Samanthan Pettai (North)	20/01/05	0923	0.220	10.8	79.849	174.5*	NA
8	Nagore (South)	19/01/05	1412	0.460	10.813	79.851	41.5	NA
9	Nagore (Middle)	19/01/05	1048	0.230	10.813	79.851	862	3.145
10	Nagore (North)	19/01/05	1304	0.420	10.813	79.851	37	NA
11	Karaikal	22/01/05	1444	0.338	10.9	79.85	199.5	2.638
12	Tarangambadi (South)	24/01/05	0942	0.461	11.031	79.855	160*	4.351*
13	Tarangambadi (Mid)	24/01/05	1055	0.319	11.033	79.85	401*	4.309*
14	Tarangambadi (North)	24/01/05	1400	0.144	11.0334	79.85	95.5*	4.644*
15	Poompuhar (South)	25/01/05	1345	0.132	11.133	79.85	225*	NA
16	Poompuhar (North)	25/01/05	1101	0.391	11.15	79.85	150*	NA
17	Thirumullaivasal	26/01/05	0958	0.5712	11.233	79.833	280*	3.587
18	Thoduvai	26/01/05	1206	0.352	11.266	79.84	536*	3.902*
19	Kodiyam Palayam	27/01/05	1115	0.570	11.3833	79.816	628*	2.790*
20	Velangirayan	29/01/05	1123	0.576	11.533	79.75	323.75	3.663
21	Reddiar Pettai - 1	2/2/2005	1240	0.664	11.566	79.75	75	4.171
22	Reddiar Pettai - 2	2/2/2005	1252	0.690	11.566	79.75	155	3.210
23	Kurinjipadi	2/2/2005	1133	0.584	11.6	79.75	372	3.722
24	Devanampattinam	2/2/2005	0921	0.370	11.733	79.783	370	3.868
25	Pudu Kuppam	1/2/2005	1545	0.419	11.866	79.816	105	3.069
26	Periyakalpet (South)	1/2/2005	1124	0.761	12.0167	79.85	350	5.886
27	Periyakalpet (Middle)	1/2/2005	0946	0.597	12.0168	79.866	175	5.362
28	Periyakalpet (North)	1/2/2005	0106	0.788	12.033	79.95	240	6.538
29	Nochi Kuppam	3/2/2005	1610	0.757	12.083	79.883	196	3.727
30	Ekkar Kuppam	3/2/2005	0916	0.325	12.166	79.95	49	4.525
31	Kottai Kadu Kuppam	3/2/2005	1427	0.793	12.233	79.966	31	2.498
32	Alambarai Kuppam	3/2/2005	1146	0.621	12.266	80.015	216	4.576
33	Sadurangapattinam-1	4/2/2005	1055	0.379	12.516	80.15	250	5.789
34	Sadurangapattinam-2	4/2/2005	1212	0.491	12.5168	80.15	182	5.071
35	Mahabalipuram	4/2/2005	1350	0.767	12.6	80.183	349	5.433
36	Kovalam	5/2/2005	1020	0.286	12.783	80.25	90	5.419
37	Urur Alcott Kuppam	5/2/2005	1445	0.880	13.55	80.066	113	5.037
38	Krishnapatanam	5/2/2005	1445	0.871	14.25	80.133	156	2.198

* Profiles could not be continued to inundation limit or dependable inundation limit mark could not be located.

Table 3. Inferences about direction of approach of tsunami at different sites

SITE NAME	Site ID	Tsunami Bearing	Basis of inferring direction
Vedaranyam	1	225°	Orientation of scouring zone around mud-balls
Samanthanpettai	5	240°	i) Drifting of a tsunami survivor
		240°	ii) Orientation of fallen trees
Karaikal	8	260°	Orientation of fallen trees
Tarangambadi	9	285°	i) Drifting of a tsunami survivor
		270°	ii) Orientation of fallen trees
		255°	iii) Container drift at PPN Jetty
Kodiampalayam	15	255°	Orientation of fallen trees
Nanjalingampettai	21	284°	Drifting of a tsunami survivor
Pudukuppam	23	243°	Drifting of a tsunami survivor
Periakalpet	25	225°	Orientation of a fallen coconut tree
Ekkiyarkuppam	27	280°	Trailing direction of net
Mahabalipuram	31	270°	i) Direction of fallen wall debris at Pattipulam
		260°	ii) Orientation of fallen trees

Table 4: Summary of survivors / eyewitness account about nature and behavior of tsunami at open sea coastal sites.

SITE NAME	Site ID	Approximate time of arrival of tsunami (in IST)			Recession of sea during any of the tsunami wave	Sound attributable to tsunami arrival	Appearance of the tsunami on arrival
		1st	2nd	3rd			
Arukattuthurai	2	---	---	---	Not recession at least before 1 st wave	Low rumbling	Sudden appearance of muddy coloured wall of water
Serudhur	3	09:15	---	---	---	Like airplane / helicopter flying at distance	Huge wave of black muddy water at about 1000 m offshore.
Velankanni	4	09:20	#	#	---	---	---
Samanthanpettai	5	09:15	09:45	#	Recession at least before 1 st wave	Helicopter passing at distance	---
Nagore	6	09:05	09:15	---	---	---	Black coloured wall of water
Tarangambadi	9	09:07*	10:09*	10:50*	---	---	Sudden appearance of muddy coloured wall of water
Poompuhar	11	08:45	---	---	Recession after 1 st inundation	No sound	Swift rising tide followed by big wave
Thirumullaivassal	12	08:45	08:50	08:55	---	Wind passing through narrow passage	Muddy coloured wall of water with waves breaking at top
Kodiampalayam	15	08:30	09:00	09:15	---	---	Muddy coloured wall of water with foam
Port Novo	18	08:40	#	#	---	---	As many large waves

* Timing noted at Pillaiperumalnallur (PPN) power plant area situated about 5 km north of Tarangampadi.

People could confirm about arrival of a second tsunami but could not even guess about arrival time

--- No information available

Table 4 (contd.):

SITE NAME	Site ID	Approximate time of arrival of tsunami (in IST)			Recession of sea during tsunami	Sound associated with tsunami arrival	Appearance of the tsunami on arrival
		1st	2nd	3rd			
Velangirayanpettai	19	09:00	---	---	---	---	---
Reddiarpettai	20	08:55	#	---	---	---	Sudden arrival of very high breaking wave
Nanjalingampettai	21	#	#	---	Recession at least after 1 st inundation	No abnormal sound	Sudden very high muddy coloured wall of water
Devanampattinam	22	>08:55	---	---	---	---	---
Pudukuppam	23	08:45	09:00	---	Recession at least after 1 st inundation	---	Swift rising tide followed by a huge wave
Pondichery Port	24	08:30	09:20	---	Recession at least after 1 st inundation	---	Swift rising tide
Periakalpet	25	08:50	---	---	Recession at least after 1 st inundation	No abnormal sound	Sudden big wave
Nochikuppam	26	08:30	#	---	No recession at least before 1 st inundation	---	Swift rising tide followed by a huge wave
Ekkiyarkuppam	27	08:30	08:45	09:00	Recession at least after 1 st inundation	No abnormal sound	First arrival as swift rising tide.
Sadurangapattinam (Sadras)	30	#	#	---	Recession at least after 1 st inundation	No abnormal sound	First arrival as swift rising tide
Kovalamkuppam	32	08:30	08:35	08:50	Recession following first swift rise	---	First arrival as swift rising tide
Karikatukuppam	33	---	---	---	---	---	First arrival as swift rising tide.
Urur Alcottkuppam	35	---	---	---	Recession following first swift rise	---	First arrival as swift rising tide followed by recession of sea
Krishnapattanam	38	09:15	11:00	---	Recession at least after 1 st inundation	---	Sudden appearance of about 4m high wall of water

Table 5: Distribution of chemical parameters in the surface seawater at different sites.

Date of sampling	Site	Site ID	Latitude	Longitude	DO (ml/l)	PO ₄ (µM)	SiO ₄ (µM)
21.1.05	Vedaranyam	1	010.3745	079.8639	N.A	1.62	71.15
19.1.05	Nagore	5	010.8132	079.8512	3.27	0.17	16.52
22.1.05	Karaikal	7	010.9140	079.8523	4.64	1.29	144.25
24.1.05	Tarangampadi	9	011.0361	079.8553	N.A	0.86	201.72
25.1.05	Poompuhar	11	011.1500	079.8574	4.65	0.38	8.05
26.1.05	Thoduvai	13	011.2732	079.8408	3.73	0.34	7.46
27.1.05	Kodiyam Palayam	15	011.3857	079.8209	N.A	0.18	236.36
28.1.05	Pichavaram	16	011.4296	079.7811	4.74	1.29	84.43
29.1.05	Velangirayanpettai	19	011.5375	079.7624	5.89	0.38	14.16
29.1.05	Pondicherry Port	24	011.9229	079.8340	1.72	0.33	2.72

N. A- Not analysed

Table 6. Summary information of confirmable tsunami transported sediment deposit

Site ID	SITE NAME	Station ID	Position DD.dddd	Brief description of the samples including thickness of post tsunami deposit
31a	PATTIPULAM (north of Mahabalipuram)	PTPM/HTL/TSD	12.7920 N 80.2214 E	About 50cm thick tsunami deposit on the floor of the collapsed building.
25	PERIYAKALAPET	SML:PKPT/MT/HTL	12.0342 N 79.8716 E	About 20cm thick sand deposited over an apparent pre-tsunami surface of decomposing black-mud. The pit was near the high tide line.
20	REDDIYAR PETTAI	RYRP/VT/PIT/T1-T3	11.5762N 79.7574E	About 23 cm thick deposit from a pit located at a distance of 20m from the low water line. The top 12cm is composed entirely of black sand. This layer is underlain by a 6cm thick layer of brown sand, below which lies a 5cm thick layer of black sand. The entire beach surface deposit was found to be composed of calcareous sands.
16	PICHAVARAM	PVRM/JT/CD	11.4296N 79.7811E	About 5cm thick fine clay deposits at jetty, with salt precipitations on the top.
15	KODIYAMPALAYAM	KDMP/MT/PIT/T1-T3	11.3846N 79.8102E	About 14 cm thick fine sand deposited over a pre-tsunami grass roots.
11	POOMPUHAR	PMPR/ST/TSD	11.1402N 79. 8601E	About 1 to 3mm thick clayey flakes from an inundated paddy field.
06	SAMANTHANPETTAI	SMNP/NT/TSD	10.7973 N 79.8510 E	About 6.5 cm thick sand deposited over a grass patch. This location is about 200m from low water line.

Table 6. Contd.

Site ID	SITE NAME	Station ID	Position DD.dddd	Brief description of the samples including thickness of post tsunami deposit
06	SAMANTHANPETTAI	SMNP/NT/SPS/	10.7995 N 79.8517 E	About 1 cm thick sandy material deposited over uprooted trees near the dune area.
06	SAMANTHANPETTAI	SMNP/ST/HOS	10.7992 N 79.8502 E	About 20-25 cm thick fine sand deposited in the floor of an abandoned house.
06	SAMANTHANPETTAI	SMNP/ST/RDS	10.8132 N 79.8512 E	About 10cm thick fine sand deposited over the village metal road.
01	VEDARANYAM	VRNM/RDS/TSD1-2	10.3757 N 79.8631 E	About 20 cm thick fine sand material from a pit.



Plate 1. Tsunami water mark on the walls of a building in Periyakalpet. Such marks were used to deduce run-up and inundation limit.



Plate.2. Partial absorption of tsunami energy caused felling of seafont row of casuarinas trees. Such fallen trees were used to infer bearing of the tsunami. (Nagore)



Plate 3. A dug out pit showing distinct tsunami transported sediments overlies dead pre-tsunami grass patch (Krishnapatnam)



Plate 4. A tsunami survivor narrating his experience to the survey team (Poompuhar).



Plate 5. Failure of compound walls. Failures of such non-load bearing short walls are inevitable as they are not designed for lateral impact loads such as tsunami. (Reddiyarpettai)



Plate 6. Damaged Cauery temple (Poompuhar) few tens of meters from sea. Isolated and smaller dimensional structures like this are less stable under undiffused tsunami flow due to lesser number of structural members in the lateral dimension.



Plate 7. Proximity of this damaged Cauery temple (Poompuhar) to the sea can be perceived through this unobstructed view of sea in front.



Plate 8. Structures with load bearing walls in close proximity to the sea which failed by the tsunami.



Plate 9. Tsunami damaged inappropriately designed structure built very close to the sea (Periyakalpet).



Plate 10. Front row houses built over elevated ground damaged due to tsunamigenic collapse of ground (Serudhur).



Plate 11. Failure of front row structures built right on the beach few tens of meters away from the sea (Karikattukuppam).



Plate 12. Power transmission tower at Nagapattinam failed by tsunami. The structure is of space-frame type with steel flats and angles



Plate 13. Tsunami damaged reinforced concrete structure on the beach (Cuddalore)



Plate 14. Total failure of isolated and small dimensioned structure in the front and unaffected larger structures in the background (Nagapattinam harbor).



Plate 15. Minimally affected large cylindrical oil storage tanks in the background and the damaged small generator room in the right side (Nagapattinam harbour).



Plate 16. Unaffected light house (circular in plan) at the background and failed structure (rectangular in plan) at the front (Nagapattinam harbour).



Plate 17. A concrete structure on stilts built right on the beach but remained unaffected by tsunami (Tirumullaivasal).



Plate 18. Failed mud plastered brick house (Velankanni).



Plate 19. Failed concrete structure (Roof) built with poor quality construction practices (Periyakalpet).



Plate 20. Example of scour failure in one of the piers of very old arched road bridge constructed with brick in lime mortar (Arasalaru river bridge, Karaikal).



Plate 21. Example of unaffected house built on elevated plinth in the low lying areas (Karaikal).



Plate 22. Example of failed structure constructed in lower level (Left) as compared to the unaffected house (right) constructed on higher ground level (Velankanni).



Plate 23. Tsunami damaged structures founded on loose sandy soil (Periyakalpet).



Plate 24. Intertwined stems of mangrove plantation which appeared to have retarded the tsunami flow (Pitchavaram).



Plate 25. Rubble mound seawall which has considerably reduced the tsunami impact over the structures behind (Tarangambadi).



Plate 26. Structures damaged by uplifted fishing trawlers (Nagapattinam).

Appendix –I

Brief description of the contents of the CD enclosed with this report

- a) This CD contains a soft copy report of the post-tsunami reconnaissance investigations conducted by the National Institute of Oceanography, Dona Paula, Goa, along the east coast of India following the tsunami of 26th December 2004 and photographs taken during the investigation.
- b) The contents in folder 'Post-tsunami investigation - east coast' have been organized in following seven subfolders ;
 - i) README
 - ii) REPORT
 - iii) Erosional & Depositional features
 - iv) Structural damages
 - v) Inundation evidences
 - vi) Assorted others
 - vii) Tsunami as observed
- c) The folder 'README' contains the text of this Appendix.
- d) The folder REPORT contains a copy of this report in 'pdf' format.
- e) The folder '**Erosional & Depositional features**' contains photos, which exhibits the various tsunamigenic erosional and depositional features observed at various sites.
- f) The folder '**Structural damages**' contains photos, which shows the various types of damages to the structures caused by Tsunami as well some structures, which experienced no or least damages.
- g) The folder '**Inundation evidences**' contains photos, which exhibits evidences of inundation of the tsunami at various locations.
- h) The folder '**Assorted others**' contains tsunami related photos, which could not be grouped under the above headings but are felt to be very interesting.
- i) The folder '**Tsunami as observed**' contains valuable photos, which were taken on the tsunami day by alert local photographers and provided to the survey team. The photographs of Karaikal and Nagapattinam area were taken

by Mr. Jana, proprietor of “Malar Digital Photo Studio”, Karaikal and the photographs of Pondicherry area was taken by officers of the Pondicherry Port Trust.

- j) The photographs are arranged as Microsoft power point slides along with detailed caption in the slide and brief caption in the thumbnail.